SURFACE WATER QUALITY ANALYSIS
TECHNICAL REPORT

SURFACE WATER MODELING OF WATER QUALITY IMPACTS ASSOCIATED WITH COAL BED METHANE DEVELOPMENT IN THE POWDER RIVER BASIN

Prepared in support of:

***Final Environmental Impact Statement and Proposed Plan Amendment for the Powder River Basin Oil and Gas Project* for:**

Bureau of Land Management
Buffalo Field Office
Buffalo, Wyoming

and

***Statewide Oil and Gas Final Environmental Impact Statement and Amendment of the Powder River and Billings Resource Management Plans* for:**

Bureau of Land Management
Miles City Field Office
Billings Field Office
Billings, Montana

Prepared by:

Greystone Environmental Consultants, Inc.
Denver, Colorado

and

ALL Consulting
Tulsa, Oklahoma

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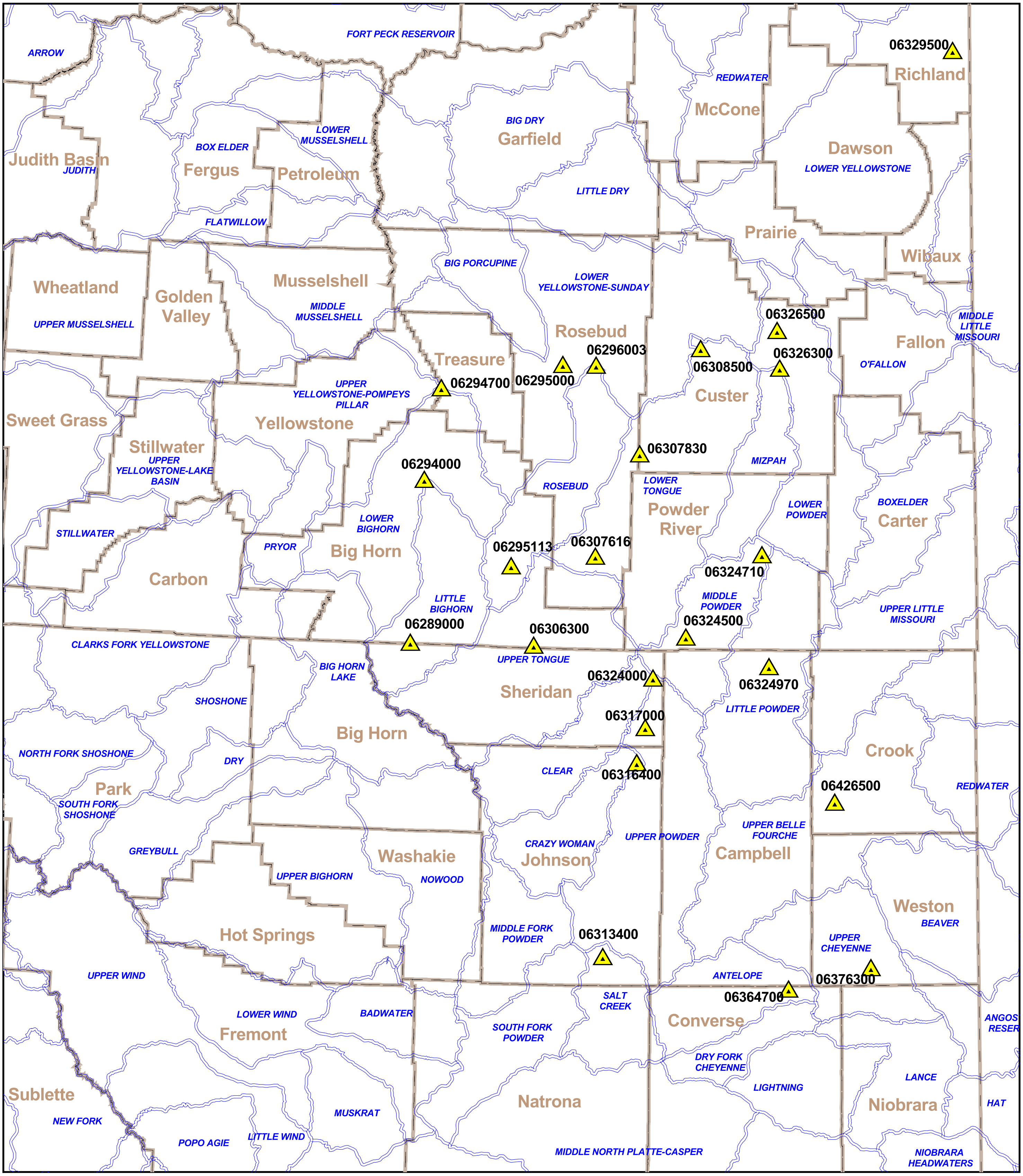
1.0 INTRODUCTION

This technical report on surface water is a support document for two separate Environmental Impact Statements (EIS): the *Final Environmental Impact Statement and Proposed Plan Amendment for the Powder River Basin Oil and Gas Project* (Wyoming FEIS), prepared for the field office of the Bureau of Land Management (BLM) in Buffalo, Wyoming, and the *Statewide Oil and Gas Final Environmental Impact Statement and Amendment of the Powder River and Billings Resource Management Plans* (Montana FEIS), prepared for the field offices of the BLM in Miles City, Montana, and Billings, Montana. The two FEISs are intended to provide an overall projection of impacts associated with development of coal bed methane (CBM) and to address the specific issues that were raised in public meetings about a proposal to develop CBM in the Powder River Basin (PRB). The proposed development of CBM in Wyoming and Montana could not be evaluated in a single National Environmental Policy Act (NEPA) document as a result of the substantial differences in the purposes of and needs for the proposed actions. However, impacts to surface water quality were analyzed cumulatively to address the effects from CBM development in Wyoming on waters that may flow downstream into Montana. This technical document describes the modeling that was used to evaluate the potential impacts to surface water quality associated with proposed CBM development in both states. The analysis described here is focused on the PRB in Wyoming and Montana, as shown in Figure 1-1. The BLM in Wyoming and Montana have coordinated the assumptions and methodologies used in the surface water modeling to support parallel impact analyses in both parts of the PRB.

CBM development has the potential to affect surface water resources. Concern arises from the potential of CBM development to reduce surface water quality. Each productive CBM well completed in the target coal seams produces water in quantities that can be large over the life of an individual well. Produced water would be managed in several ways, including: discharge to local surface drainages (with or without prior treatment), infiltration via shallow impoundments, storage in reservoirs (containment), injection into deeper geologic units via wells, and land application. Options for water management would facilitate beneficial use, where feasible. Modeling was used to predict the effects to surface water quality of increased CBM operations on the main stem streams in the PRB under various water management scenarios.



Legend

- Monitoring Station
- Sub-watershed Boundary
- County Boundary

N
W E
S

Scale 1 : 2,600,000

40 0 40 Miles

50 0 50 Kilometers

POWDER RIVER BASIN
SURFACE WATER
TECHNICAL SUPPORT DOCUMENT

FIGURE 1-1
ANALYSIS AREA
POWDER RIVER BASIN, WYOMING and MONTANA

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	Prepared By: MSH

2.0 PROJECT DESCRIPTION

A detailed description of the hydrologic framework of the PRB was provided in Chapter 3 of the two FEIS documents. Additional information is presented below to establish the basis for the modeling. Surface waters in Wyoming were represented for the modeling effort by the main stem streams of 10 fourth-order watersheds (known as sub-watersheds). These sub-watersheds include the Upper Tongue, Middle Powder, and Little Powder sub-watersheds, which straddle the border between Wyoming and Montana, and the Upper Powder, Clear Creek, Crazy Woman Creek, Salt Creek, Upper Belle Fourche, Upper Cheyenne, and Antelope Creek sub-watersheds. Surface waters in Montana were represented by the main stem streams of 11 sub-watersheds. These sub-watersheds include the Lower Tongue, Little Bighorn, Lower Bighorn, Rosebud Creek, Mizpah Creek, Lower Powder, Lower Yellowstone-Sunday, and Lower Yellowstone, in addition to the three sub-watersheds that straddle the boundary between both states. This analysis used the terms watershed and sub-watershed interchangeably.

2.1 Alternatives Analyzed

Details of each alternative analyzed are described in Chapter 2 of the two FEIS documents. The following summaries address the differences in each alternative with respect to development of the model.

2.1.1 Wyoming FEIS

The Wyoming FEIS sets forth three alternatives plus the no-action alternative for development of CBM in the PRB. The alternatives differ primarily in the means of managing produced water.

2.1.1.1 Alternative 1

Under Alternative 1, flows of CBM produced water would be handled through direct discharge to surface drainages, passive treatment prior to surface discharge, discharge to upland and bottomland infiltration impoundments, discharge to containment impoundments, land application disposal (LAD), and injection. This analysis assumed that 15 percent of the CBM water discharged to infiltration impoundments would resurface in-channel and contribute to existing stream flows. The analysis also assumed that water produced from CBM wells and managed through containment, LAD, and injection would not contribute to existing stream flows.

The Wyoming BLM analyzed data on water production from existing wells downloaded from the Wyoming Oil and Gas Conservation Commission (WOGCC) web page to project total water production on an annual, and an over the life of the project basis by sub-watershed (Meyer 2002a). Under Alternative 1, the maximum volume of CBM water produced annually is expected to increase from an estimated 109,429 acre-feet per year in 2001, produced from existing CBM wells, to an estimated 386,336 acre-feet per year, occurring in year 2006. The peak year of water production by sub-watershed varies, and these years were modeled in the surface water impact analysis to evaluate effects from discharges of CBM produced water.

2.1.1.2 Alternative 2A

Under Alternative 2A, CBM produced water would be handled by the same methods that were specified in Alternative 1. Use of upland and bottomland infiltration impoundments would be emphasized, however. The contribution of CBM water to existing stream flows from the various water handling options would be the same as under Alternative 1; however, the percentage of CBM water managed through each option would vary. There would be no direct surface discharge in the Salt Creek sub-watershed. The volume of water produced and the peak year of water production would be the same as under Alternative 1.

2.1.1.3 Alternative 2B

Under Alternative 2B, CBM produced water would be handled by the same methods specified in Alternative 1. Use of active treatment, such as reverse osmosis, or ion exchange systems, to amend the produced water to meet water quality standards prior to discharge would be emphasized, however. Some level of active treatment would be implemented in all sub-watersheds except for the Upper Belle Fourche River sub-watershed. The level of treatment would depend on the constituents of concern, and designated uses downstream. This analysis assumed that the proportion of CBM produced water to undergo active treatment would be 100 percent consumptively used. Thus, the volume is not included in projecting impacts to surface flows. The contribution of CBM water to existing stream flows from the various water handling options would be the same as under Alternative 1; however, the percentage of CBM water managed through each option would vary. There would be no direct surface discharge in the Salt Creek sub-watershed. The volume of water produced and the peak year of water production would be the same as under Alternative 1.

2.1.1.4 Alternative 3

Under Alternative 3, no new federal CBM wells would be completed, except for areas of potential drainage. Water handling options would be the same as under Alternative 1, and include direct discharge to surface drainages, passive treatment prior to surface discharge, discharge to upland and bottomland infiltration impoundments, discharge to containment impoundments, LAD, and injection. The contribution of CBM produced water to existing stream flows from the various water handling options would be the same as under Alternative 1.

Under Alternative 3, the maximum volume of CBM water produced annually is expected to increase from an estimated 109,429 acre-feet per year in 2001, produced from existing CBM wells, to an estimated 212,919 acre-feet per year, occurring in year 2005. The peak year of water production by sub-watershed varies, and these years were modeled in the surface water impact analysis to evaluate effects from discharges of CBM produced water.

2.1.2 Montana FEIS

The Montana FEIS proposes five alternatives for development of CBM in the PRB. These alternatives differ in degree of protection afforded to water resources and in the restrictions that would be imposed on development of CBM.

2.1.2.1 Alternative A

Under Alternative A, the Montana BLM would approve drilling and testing of CBM wells on federal leases but would not authorize production of CBM from federal minerals or installation of production facilities. Waters produced during the testing phase would be contained either in produced water pits or in tanks and would not be discharged into state or federal waters. The produced water would be available for beneficial use by industry and landowners.

Under this alternative, the State of Montana would allow up to 200 CBM exploration wells to be drilled to evaluate water quality and quantity or the suitability of the coal resource. Surface discharge of produced waters from these wells to state or federal waters would be prohibited. Redstone Gas Partners would be allowed to expand the existing CX Ranch Field pilot project in the Upper Tongue River sub-watershed near Decker, Montana, which would increase the number of producing wells from this field to a maximum of 250. Discharge of production water from these additional producing CX Ranch wells would be incorporated into the current Montana Pollutant Discharge Elimination System (MPDES) permit, which allows a maximum discharge of 1,600 gallons per minute (gpm) into the Upper Tongue River from as many as 11 discharge locations. Beneficial reuse of discharges of CBM produced water would be expected to continue near the CX Ranch field.

The Rosebud Creek, the Little Bighorn/Lower Bighorn, and Mizpah Creek sub-watersheds would not receive any CBM produced water under this alternative; however, an analysis of their flow volumes and water quality is included for comparison with other alternatives. Impacts are possible to the Upper Tongue River, Middle Powder River, and Little Powder River sub-watersheds from CBM development under Alternative A as a result of the addition of the forecast future development of CBM resources in the Wyoming portion of the PRB that adjoins Montana.

2.1.2.2 Alternative B

This alternative would allow CBM development while emphasizing protection of water resources. Water from exploration wells would be temporarily stored in tanks or other approved storage facilities and then injected into an aquifer different from where it originated via Class II or V injection wells. Surface discharge of produced waters from producing wells to state or federal waters would not occur under this alternative.

Produced water from existing wells in the CX Ranch field would continue to discharge to the Upper Tongue River sub-watershed, as described under alternative A.

2.1.2.3 Alternative C

This alternative would emphasize CBM exploration and development with minimal restrictions. Management of produced water would include a combination of beneficial use and surface discharge. Beneficial uses would include stock water, dust suppression, irrigation, and other industrial uses. Surface discharge could occur, but would be subject to the limitations of the MPDES permit and conditions established for discharge into identified drainages.

Produced water discharged to the surface would be released in several ways: directly to surface water or drainages, or into on-drainage and off-drainage impoundments. This alternative assumed that 100 percent of the CBM produced water would be discharged to surface streams and that 20 percent of the water would be lost to infiltration, evaporation, and evapotranspiration, collectively referred to as “in-channel losses.” All surface discharges would be in compliance with a MPDES permit.

Surface waters that could be affected by CBM development under this alternative include streams in the Upper Tongue, Powder, Little Powder, Little Bighorn, Bighorn, Mizpah, Rosebud, and Yellowstone sub-watersheds.

2.1.2.4 Alternative D

This alternative would encourage CBM development while maintaining existing land uses and protecting downstream water consumers. All produced water would be treated prior to surface discharge or containment in impoundments. Water would be conveyed via a constructed drainage system or pipeline to the nearest perennial watercourse. Treatment of the water would be unrestricted, provided the resulting effluent met standards established by the Montana Department of Environmental Quality (MDEQ) for downstream use. Treatment for beneficial purposes would vary depending on the type of use. Surface storage of produced waters would also require an MPDES permit issued by the MDEQ.

This analysis assumed that 80 percent of CBM produced water would be treated and discharged under this alternative.No conveyance losses would be deducted because the water would be piped to the receiving body of water.

2.1.2.5 Preferred Alternative E

The Preferred Alternative would provide management options to facilitate exploration and development of CBM while sustaining water resource values and existing land uses. This alternative combines management options so no unnecessary or undue degradation of water quality would be allowed in any watershed. The water management option emphasized would be beneficial use. Other options include injection, treatment, containment, or discharge. Water Management Plans (WMP) would be required for all exploration and development projects. WMPs and permits would be approved by the appropriate agency in consultation with affected surface owners. There would be no discharge (treated or untreated) into the watershed except under two conditions: the operator must obtain an approved MPDES permit, and could demonstrate in the WMP how discharge could occur in accordance with water quality laws without damage to the watershed.

Under this alternative, the combination of emphasized beneficial use and increased flexibility for managing produced water would increase water used for beneficial purposes, such as stock watering, irrigation, and dust control. This analysis assumed that surface discharge from CBM development in Wyoming and Montana would occur in each watershed until the resulting quality of the mixed water reaches the limits proposed for Montana streams. The remaining CBM produced water would be managed by other options, including injection, treatment, infiltration or evaporation ponds, and beneficial use.

3.0 APPROACH TO SURFACE WATER MODEL

3.1 Discussion of Proposed Standards

A major beneficial use of surface water in the Project Area is the production of irrigated crops. Therefore, this document focuses on the potential effects to the suitability for irrigation of surface waters in the PRB from proposed discharges of CBM produced water. The effects of the quantity and quality of CBM produced waters on other resources are discussed in relevant sections of the FEISs.

The key water quality parameters for predicting the potential effects of CBM development on irrigated agriculture are sodicity (as measured in the sodium adsorption ratio, or SAR) and salinity (as measured by electrical conductivity, EC). In-stream numerical targets for these parameters, therefore, would facilitate modeling and interpreting impacts under the various alternatives. Ideally, those numerical targets would be in the form of numerical water quality standards — in other words, values backed by regulatory authority. At this time, with the exception of waters that flow from Wyoming into South Dakota, no regulatory water quality standards for these parameters are applicable to the water bodies addressed in this analysis, or for the water bodies downstream in Montana that are likely to receive flows of CBM produced water from Wyoming.

Therefore, because of the importance of this issue, the regulatory entities with jurisdiction for the potentially affected water bodies have begun to quantify the SAR and EC values they believe will be needed to ensure protection of irrigated agriculture in and downstream of the Project Area. In May 2002, for example, the Northern Cheyenne Tribe adopted numerical water quality limits for SAR and EC that are applicable to waters within the reservation, which receives flows in the Tongue River from Wyoming. These tribal limits will not have regulatory status under the Clean Water Act (CWA) until they are approved by the U.S. Environmental Protection Agency (EPA). Still, the adopted numerical limits clearly set out the tribe's considered determination of the water quality needed to protect irrigated agriculture on the reservation.

Wyoming's current permitting process incorporates the numeric water quality standards for EC and SAR adopted in water bodies downstream in South Dakota, specifically the drainages in the Upper Cheyenne and Upper Belle Fourche River sub-watersheds. Wyoming and Montana have entered an interim memorandum of cooperation (MOC) to protect the downstream water quality in the Powder and Little Powder River sub-watersheds in Montana while continuing to allow for CBM development in both states. Interim thresholds are established for EC in the Powder River at the state line, based on monitoring data collected at the gauging station in Moorhead, Montana. The criteria for EC are expressed in monthly maximum values that are not to be exceeded. The two states are also concerned with SAR and bicarbonate but lack sufficient data to establish threshold criteria. Under the MOC, monitoring of the Little Powder River will include EC, SAR, and total dissolved solids (TDS) to evaluate whether these levels change appreciably from historical records. The State of Wyoming would be required to undertake a cause investigation in the event significant changes from baseline conditions are detected in order to determine if CBM discharge is responsible. Wyoming may be required to adjust its regulatory position with the permitting process to ensure compliance with the spirit of the agreement.Wyoming is restricting the amount of CBM discharge water that reaches the main stems through its National Pollutant Discharge Elimination System (NPDES) permitting process to meet the short-term goal of the MOC. Discharge has been restricted through such mechanisms as pond storage, channel loss, and other consumptive uses. Furthermore, as a matter of policy, the Wyoming Department of Environmental Quality (WDEQ) has elected to impose its anti-degradation policy on all CBM discharges. This policy results in effluent limitations in NPDES permits for discharges of CBM produced water that equate to 20 percent of the available increment between low-flow pollutant concentrations and the relevant standards (assimilative capacity) for critical constituents. A separate anti-degradation policy for barium, that sets a basin-specific assimilative capacity, is also applied to discharges of CBM produced waters. Montana has accepted Wyoming's anti-degradation policies as protective of Montana's water quality.

Montana has initiated a process for developing and adopting water quality standards for SAR and EC as well, with the goal of a final decision by the Montana Board of Environmental Review (MBER) by December 2002. MDEQ has proposed two approaches in Montana: one would assign a single set of SAR and EC values to each of the potentially affected water bodies (option 1), and the second would assign a series of values that would be applicable to the main stem of the Tongue River (option 2). MDEQ lists a range of values to be considered by the board for each approach. In addition, a coalition of environmental and irrigation interest groups, collectively known as the "Petitioners," has proposed its own set of numerical SAR and EC limits. The Petitioners include the Tongue River Water Users; the Tongue and Yellowstone Irrigation District; the Buffalo Rapids Irrigation Project; and the Northern Plains Resource Council. The Petitioners' proposal takes an approach similar to MDEQ's option 2. Finally, some time ago, South Dakota's Department of Environment and Natural Resources (SDDENR) adopted numerical SAR and EC standards that are applicable statewide.

There are, then, five sets of numerical limits for SAR and EC now under consideration or applicable to the water bodies addressed in this analysis: the Northern Cheyenne Tribe's adopted water quality limits; Montana's option 1; Montana's option 2; the Petitioners' proposal; and South Dakota's adopted statewide water quality standards. Together, these five sets of values present a wide range of numerical values. Table 3-1 displays the full range of values, including both the lowest and highest possible upper limits, where applicable, for SAR and EC. The water quality standards development process is still under way for key water bodies addressed in this analysis, however. Therefore, it would be inappropriate for the lead or cooperating agencies to this document and the relevant FEISs to select specific numerical values within the range and to apply only those selected values in evaluating potential impact scenarios. Instead, this document uses the full range of potential SAR and EC values as the guideposts to display the outputs of surface water modeling.

The information displayed should be applied only mindful of the three following considerations: First, it should not be assumed that any SAR or EC value within the displayed range will be determined to provide an appropriate level of protection for the existing or anticipated irrigated agricultural uses in these basins. Second, the process of developing water quality standards involves adoption by a state or tribe followed by EPA review and approval, and state- or tribally adopted limits will not assume CWA regulatory status until they have been approved by EPA. Third, the process of developing water quality standards is still under way, and it is not possible to predict the outcome.

Nevertheless, although the eventual outcome of this process for setting water quality standards is uncertain at present, it may be useful to note the specific SAR and EC values adopted by the Northern Cheyenne Tribe and the SDDENR, and those proposed by the MDEQ and the Petitioners. It may further be useful to include those values in the specific impact scenarios evaluated. These SAR and EC values were developed with assistance from advisors with expertise in the areas of the effects of salinity and sodicity on irrigated agriculture. Therefore, it would not be unreasonable to view these values for SAR and EC as a fair estimate of the range that may eventually be judged as providing an appropriate level of protection for irrigated agriculture in the sub-watersheds addressed in this analysis. The specific SAR and EC values proposed or adopted for these sub-watersheds are presented in Appendix A, allowing for application of specific, proposed or adopted numerical standards in the evaluation of various impact scenarios.

The second factor to be considered in applying the information displayed is the significant distinction between the surface water modeling approach applied to alternatives analyzed in this EIS and the approach that eventually will be used in calculating discharge limits for future, specific CBM development projects. The modeling approach used in this document begins with an assumed water management method for the proposed development under each alternative and, applying a series of assumptions (see discussion below), predicts a resulting in-stream water quality. The predicted output of the water quality modeling is then displayed against the full range of potential limits on SAR and EC for each sub-watershed, with no assessment as to the appropriateness of any specific value within the range. The water quality-based approach that will be used to calculate future NPDES permitting requirements, conversely, will begin with appropriate and specific in-stream water quality targets. These targets may include approved water quality standards and, through the total maximum daily load (TMDL) process, those standards may be translated into discharge limits for specific CBM development projects.

The standards will serve as the regulatory basis for controlling CBM discharges. The water quality-based permitting approach that will implement those standards is, therefore, different from the predictive modeling approach used in this analysis. That is, the water quality-based approach will begin with a desired in-stream water quality and, using that level as the target, will calculate the limits on CBM discharge needed to ensure the desired in-stream water quality. Finally, assimilative capacity identified through the TMDL process for a water body will have to be allocated among the appropriate governmental entities along the water body. EPA has a trust responsibility to ensure that a fair and meaningful portion of the available assimilative capacity is reserved for a tribe that is one of the appropriate governmental entities.

3.2 Evaluation Criteria

3.2.1 Most Restrictive Proposed Limit/Least Resrictive Proposed Limit

Table 3-1 summarizes the highest and lowest standards for EC and SAR proposed for or applicable to the sub-watersheds addressed in the analysis. Construction of this table considered the full range of values proposed in the Montana standards process now underway, the adopted Northern Cheyenne standards, South Dakota standards, and the limits applied by the WDEQ to waters that flow downstream into South Dakota. A more detailed summary of the proposed standards under consideration in the Montana standards process and the limits adopted by South Dakota is included in Appendix A. The proposed limits apply to individual sub-watersheds and have been suggested for various seasons of the year. For example, different limits have been proposed for the irrigation season, and the length of the irrigation season often differs for each sub-watershed. The Montana limits were compiled for this analysis as a range of values and were evaluated under a single irrigation season. South Dakota applies water quality standards for EC and SAR year-round. The limits shown in 3-1 are compared with EC and SAR values for resulting mixtures of existing stream flows and CBM discharges under various flow conditions projected under each alternative. CBM discharges to the Upper Powder River, Clear Creek, Crazy Woman Creek, and Salt Creek sub-watersheds in Wyoming have the potential to flow into the Middle Powder River sub-watershed in Montana. Therefore, the limits proposed in Montana for the Powder River have also been applied to these sub-watersheds. WDEQ applies limits in the Upper Cheyenne, Antelope Creek, and the Upper Belle Fourche sub-watersheds in authorizing discharge permits for CBM produced waters to protect the most sensitive crop (alfalfa) that may be grown downstream (Beach 2002).

3.2.2 Ayers and Westcot Irrigation Suitability Diagram

The evaluation of impacts to water quality considers the potential changes in levels of EC and SAR in irrigation water and the implications for production of agricultural crops. The evaluation was based on a criterion of no impact on soils from infiltration. The Ayers and Westcot (1985) irrigation suitability diagram was used to compare water quality before and after it has mixed with discharges of CBM produced water using the diagonal line on the diagram as a no-impact threshold for SAR and EC values of the water. Below and to the right of the irrigation threshold line, water quality would be expected to cause "no reduction in the rate of infiltration" as a result of the dispersion of soils by SAR (Ayers and Westcot 1985). To the left and above the line, waters would be likely to cause "slight to moderate reduction in the rate of infiltration" (Ayers and Westcot 1985). Elevated SAR values may reduce permeability in clayey soils, thereby reducing the rate of water infiltration. The significance of the effects from reduced

Table 3-1
Summary of Proposed Limits for Surface Water Impact Analysis

Sub-Watershed	Most Restrictive Proposed Limit (MRPL)		Least Restrictive Proposed Limit (LRPL)	
	SAR	EC (µS/cm)	SAR	EC (µS/cm)
Tongue, Bighorn, Little Bighorn, Yellowstone	0.5	500	10	2,500
Rosebud	1.0	500	10	2,500
Little Powder	3.0	1,000	10	3,000
Powder, Clear Creek, Crazy Woman Creek, Salt Creek, Mizpah	2.0	1,000	10	3,200
Belle Fourche	10 (1)	2,000 (1)	10 (2)	2,500 (2)
Cheyenne, Antelope Creek	10 (1)	2,000 (1)	10 (2)	2,500 (2)

(1) WDEQ limit applied to waters that flow downstream into South Dakota
(2) South Dakota's existing water quality standard

NOTE: The Tongue River standards proposals are being utilized to assess impacts to the Bighorn, Little Bighorn, and Yellowstone River sub-watersheds, although there are not any petitions before the MBER on these streams for this purpose.

infiltration vary with soil type, and increases on clay and clay-loam soils. Although some soil sealing may occur, at the surface, following one irrigation event in combination with a rain event, soils are more likely to be affected by the quality of a number of irrigation events in sequence. For this reason, potential changes in the quality of irrigation water were analyzed on a monthly basis..

The Ayers-Westcot diagram incorporates a relationship between SAR and EC, which recognizes that as salinity increases the potential impacts of SAR decrease. This relationship is not unbounded, however, because of the potential impact of rainfall on sodic soils. Rainfall can cause SAR problems in surface soil because of the differential way in which EC and SAR respond to a rain event (significant lowering of the EC and little change in the SAR). This rain-on-sodic-soil problem is addressed in a number of the standards proposals (see Appendix A) through adoption of an absolute maximum SAR (i.e., the standard "caps" the Ayers-Westcot EC/SAR relationship). It will be important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached in the alternatives analyses in this document. This may help explain situations where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

3.2.3 Percent of CBM Discharge

The Ayers-Westcot diagram was also used to evaluate the proportion of CBM discharge that could reasonably occur under various flow conditions without causing potential impacts to infiltration.

4.0 DEVELOPMENT OF SURFACE WATER MODEL

4.1 Methodology

The spreadsheet model used in the surface water impact analysis employs a steady–state, mass-balance approach to estimate steady-state concentrations of EC and SAR after two or more inflows are mixed. This steady-state approach is commonly used by states in EPA Region VIII to predict possible effects of point-source discharges on receiving waters. This approach has been endorsed in EPA guidance through the years (EPA 1991). The application of the mass-balance approach to SAR is supported by the analysis described in Appendix B.

4.2 Model Input Parameters

Input parameters to the model were developed from analysis of reasonably conservative assumptions as well as measures of central tendency (typical or mean values). Table 4-1 describes the input parameters and indicates whether conservative or mid-range values were used in the model for the impact analysis. A complete summary of the inputs used in the impact analysis for surface water quality is presented in Appendices C and D. The conservative assumptions (and the degree of conservatism they impart) are described below. Non-conservative (mid-range or mean value) assumptions also are described below. The resultant model is considered to provide a conservative, yet reasonable, estimate of the impacts of CBM development on surface water quality in the PRB.

Conservative assumptions:

- Mixed SAR was estimated using a simple flow-weighted mass balance equation, assuming SAR behaves as a constituent of water. This assumption results in overestimation of SAR and, potentially, of impacts by a factor of about 2 (see Appendix B).

- The maximum number of CBM wells based on reasonably foreseeable development in both Wyoming and Montana was used in the model.

- Impacts to streams were evaluated for 7Q10 flows as well as mean monthly flows. The 7Q10 flows are about a factor of 10 less than the mean monthly flow rates. The 7Q10 analysis evaluated the maximum likely impacts to surface water quality. (The 7Q10 is the minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period. The chance that the 7Q10 flow will occur in any year is 10 percent.)

Non-conservative (mid-range) assumptions:

- The model assumed complete mixing. Impacts to surface water quality may be greater than are predicted in the mixing zone near the points of discharge.

- Mean flow rates for CBM discharges were used in the model. Actual discharge rates vary by a factor of 10 or more.

- A typical value of channel loss was used in the model. This value would under-predict the impacts to surface water quality if discharge were piped directly to the river or if the discharge point is very close to the main stem river.

- Mean values for SAR and EC in CBM produced water by sub-watershed were used, while actual values within a sub-watershed vary by a factor of 2 for SAR and by a factor of 2 to 5 for EC.

- Mean values for ambient levels of SAR and EC in streams were used, while actual values for both parameters vary by a factor of 2 or more.

Table 4-1
Summary of Input Parameters

Parameter	Conservative Value	Typical Value	Magnitude of Range	Value Used in EIS
WY Estimated Number CBM Wells	RFD	---	---	Conservative
MT Estimated Number CBM Wells	RFD	---	---	Conservative
CBM Well Discharge Rate (gpm)	Max	Mean	10X	Typical (Mean)
Channel Loss (%)	0	20	10X	Typical (Mean)
CBM Produced Water EC (µS/cm)	Mean	Mean	2 to 5X	Typical (Mean)
CBM Produced Water SAR	Mean	Mean	2X	Typical (Mean)
Stream Flow (cfs)	7Q10	Mean	10X	Typical (Mean) & Conservative
Stream EC (µS/cm)	Low	Flow-weighted Mean	2X	Typical (Mean)
Stream SAR	High	Flow-weighted Mean	2X	Typical (Mean)

Note: µS/cm = Microsiemens per centimeter
gpm = Gallons per minute
RFD= Reasonable foreseeable development
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

4.2.1 Stream Quantity and Quality

4.2.1.1 Stream Flow

<u>**Wyoming**</u>

Representative flow rates for streams in the Wyoming portion of the PRB were estimated from analysis of the historical record at U.S. Geological Survey (USGS) stream gauging stations (Kuhn 2002). Statistics on flow were compiled from the mean of each month's flows. Values for 7Q10 flow were computed for stations with adequate record. These statistics on flow are summarized in Appendix C. The 7Q10 flow represented the minimum flow averaged over 7 consecutive days that would be expected to occur, on average, once in any 10-year period. Base-flow conditions in the streams were represented by the low of the mean monthly flows. The impact analysis for surface water quality evaluated the effects of CBM development on water quality using flows that ranged from a low corresponding to the 7Q10 flow statistic to a high represented by the maximum of the mean monthly flow.

Another flow regime to consider is the 1Q10 flow, which is the lowest daily flow to occur on average, once in every 10-year period. For most of the streams addressed in this analysis, there is no real difference between the 7Q10 and 1Q10 in terms of flow (almost always zero for both), however, there is an exception in the Tongue River. A number of the proposed EC and SAR values are absolute maximums, which would warrant the use of the 1Q10 flow parameter. However, WDEQ would not authorize any new CBM discharges to the Upper Tongue River sub-watershed unless the water quality of the discharge was similar to the ambient water quality in the Tongue River. In Montana, a similar reluctance is in place; the MDEQ will likely not authorize new discharges of untreated CBM water to the Tongue River watersheds except perhaps on a flow-based permit that would only allow discharge during high-flow periods. Therefore, an analysis using this flow regime has not been performed.

Montana

Representative flow rates for streams in the Montana portion of the PRB and adjacent areas were extracted from the historical data in the USGS archives of stream gauging stations (USGS 2002). Statistics on flow were assembled for mean monthly and 7Q10 flows. These statistics are summarized in Appendix C. Base-flow conditions for each gauging station were derived from the lowest of the monthly means. High flow conditions were derived from the maximum of the monthly means. The impact analysis for surface water quality modeled each of the monthly mean flow values and the 7Q10 rate computed. Potential impacts were evaluated using the base flow, high flow, and 7Q10 rates for each gauging station.

4.2.1.2 Stream Water Quality

Wyoming

EC and SAR values for streams in the Wyoming portion of the PRB were derived from analysis of the historical record at USGS stream monitoring stations (Kuhn 2002). The water quality constituents were plotted against stream flow, and power curves were fitted to the data to develop a mathematical relationship between flow and water quality (Meyer 2002a). The water quality data were compiled by the month and year when they were collected, and a mean of the values from each month was calculated. Representative SAR values were derived from the mean of sample SAR values, rather than from the mean of values for sodium, calcium, and magnesium from each sample. Either method for estimating mean SAR values yielded similar results (Appendix B). A comparison of the data projected by the power curve relationship at each monthly mean discharge versus the mean value for all water quality samples for the month indicated that neither method fully captured the natural variation of water quality attributable to changes in stream flow or seasonal fluctuations with time (Meyer 2002a). However, averaging the value computed using the power curve with the mean of the monthly water quality values appeared to yield the best approximation of water quality at mean monthly flow rates throughout the year (Meyer 2002a). Therefore, these average values were used in the water quality impact analysis as representative of stream water quality at the mean monthly discharge. Representative monthly water quality values are summarized in Appendix C.

Representative EC and SAR values for 7Q10 flows were estimated from the power curve analysis only. Both EC and SAR values were estimated for the Upper Powder River at Arvada for the month of September based on a very large difference between the power curve projection and the mean of the monthly values. EC values for 7Q10 flow were also estimated for the Middle Powder River at Moorhead because of an unrealistically large value projected by the power curve relationship.

<u>Montana</u>

EC and SAR values for streams in the Montana portion of the PRB and adjacent areas were derived from historic USGS monitoring data (USGS 2002). Monitoring data were aggregated by month to calculate mean monthly values for EC and SAR. The data were plotted against stream flow rates to derive water quality values for 7Q10 flows. Representative SAR values were estimated from the mean of sample SAR values rather than from the mean of the values for sodium, calcium, and magnesium from each sample. Either method for deriving mean SAR values yielded similar results (Appendix B). Representative monthly water quality values are summarized in Appendix C.

4.2.2 CBM Quantity and Quality

4.2.2.1 CBM Wells

<u>Wyoming</u>

This analysis was based on estimates of the number of potential new CBM wells, which is described by the BLM as the “Reasonable Foreseeable Development” (RFD). Projections for RFD of CBM in Wyoming under Alternatives 1, 2A, and 2B includes 39, 367 new wells in the Wyoming portion of the PRB over the next 10 years. Under Alternative 3, the RFD includes 15,458 new wells over 10 years. The life of each producing well would be 7 years. These estimates of RFD are divided among the sub-watersheds. The number of wells that would produce in each sub-watershed during the peak year of water production is summarized in Appendix D.

<u>Montana</u>

Using the assumptions in the RFD and the extrapolated discharge trend line that estimated the average production rate for a specified time frame, it was determined that the maximum annual volume of produced water would occur in year six of the proposed development. During year six, 12,641 wells would be producing. The number of wells that would produce in each sub-watershed during the peak year of water production is summarized in Appendix D.

4.2.2.2 CBM Discharge Rate

<u>Wyoming</u>

The BLM analyzed water production data from existing wells downloaded from the WOGCC web page to project total water production on an annual and over the life of the project basis by sub-watershed (Meyer 2002b). Mean monthly water production by sub-watershed was plotted and visually examined to identify the point where maximum water production was reached and a decline in monthly water production could be observed. A logarithmic decline curve was fitted to the data points after maximum production ends, and the equation of the curve was computed and used to predict annual water production for a typical well in each sub-watershed. For the Antelope Creek sub-watershed, where sufficient production history was not available to produce a suitable decline curve, estimates of water production were based on the production history from the Upper Belle Fourche sub-watershed. Water production data for all existing wells in the Middle Powder, Upper Powder, Clear Creek, Crazy Woman Creek, and Salt Creek sub-watersheds were combined to compute a single decline curve, which was applied to all of these sub-watersheds. Applying the average decline curve for the sub-watershed to the number of wells proposed for each year made it possible to project annual water production over the life of the project (Meyer 2002b). The year of peak water production was calculated from this analysis. The average discharge rate per well was estimated using the peak discharge in each sub-watershed divided by the total number of wells discharged in the peak year in each sub-watershed.

The number of wells and corresponding flow rate per well in the peak year of water production were used as input in the impact analysis for surface water quality for the Upper Belle Fourche, Antelope Creek, and the Upper Cheyenne River sub-watersheds. The average peak discharge rate in these sub-watersheds is 7.0, 11.9, and 9.6 gpm/well, respectively. A value of 6.2 gpm/well, which represents a basin-wide (WY and MT) average production rate during the peak year of water production was used in the Powder River, Little Powder River, and Upper Tongue River sub-watersheds to facilitate a parallel analysis of impacts to water quality from CBM development in both states.

Montana

Discharge rates for CBM produced water used in the model were derived by estimating the highest water production rate for all wells proposed for the Montana portion of the PRB. This estimate was a combination of the projected number of active CBM wells according to the RFD, concatenated against the calculated decline curve for water production (ALL 2001). The result of the forecasts and calculations show that the Montana portion of the PRB would contain 12,641 CBM wells during the sixth year of CBM development. In addition, the average well would produce water at rate of 6.2 gpm, for a total of 5.4 billion cubic feet produced during that year. The total wells were assigned to specific sub-watersheds to project the total rate of water production that would be discharged to the main stem streams or managed by other options.

4.2.2.3 CBM Water Quality

Wyoming

The BLM summarized and modeled EC and SAR values for CBM produced water from 132 wells by sub-watershed (Meyer 2002c). EC and SAR values were derived from the chemical analysis from each well. Universal Transverse Mercator (UTM) coordinates were assigned to each sample point, and the data were imported into contouring software for analysis. Kriging was employed to transform the irregularly spaced sample points into a grid of uniform spacing over the entire PRB (Meyer 2002c). Grid points were then exported as X-Y-Z coordinates to allow spatial analysis and data interpretation using ArcView (Meyer 2002c). Grid points were imported into ArcView and clipped to the approximate outcrop of the Wyodak-Anderson coal zone. The grid points were intersected with an overlay that contained the boundaries of the sub-watershed. Mean EC and SAR values were calculated from the sub-watershed grid points. Analysis of the extracted points yielded a basin-weighted value because uniform grid spacing was applied to the entire basin (Meyer 2002c).

The EC and SAR values used in the analysis of impacts to water quality in the Upper Cheyenne River sub-watershed were calculated using a flow-weighted average of the combined discharges from the Antelope Creek and Upper Cheyenne River sub-watersheds. The EC and SAR values used in the analysis of impacts to water quality in the Middle Powder River sub-watershed were calculated using a flow-weighted average of the combined discharges from the Salt Creek, Clear Creek, Crazy Woman Creek, Upper Powder River, and Middle Powder River sub-watersheds.The CX Ranch data that represented the high-end value for EC and SAR were used for the Montana contribution at the state line stations in the Middle Powder and the Upper Tongue.

Montana

The quality of CBM produced water used in the model was derived on a sub-watershed basis. Limited data on the quality of CBM water were available for Montana; the CX Ranch field located near Decker, Montana, was the only source of data on CBM produced water in the state. Future CBM development may produce water of different chemistry and quality. Therefore, a range of water quality values was used in the model to cover the range of possible water quality conditions that may be encountered in the Montana portion of the PRB.

For the Tongue River, Bighorn/Little Bighorn, and Rosebud Creek sub-watersheds, the range of water quality values included mean values from the CX Ranch field (SAR = 47, EC = 2,207 µS/cm), to mean values from the Upper Tongue River sub-watershed in Wyoming (SAR = 38.7, EC = 2,406 µS/cm). For the Powder River, Mizpah Creek, and the Lower Yellowstone sub-watersheds, the range of values included the Wyoming mean to the Wyoming maximum. These values are summarized in Appendix D.

4.2.3 Water Losses

4.2.3.1 Managed Water Loss

Wyoming

Water produced from CBM wells and managed through containment, LAD, and injection would not have direct effects on quality and quantity of surface water, because, by definition (see chapter 2, WY FEIS) none of the discharged water under these water handling options would reach drainages in the sub-watersheds. This analysis assumed that CBM produced water that would be actively treated would be 100 percent consumptively used because of the higher quality.

The percentage of CBM water production handled by active treatment, containment, LAD, and injection, and the proportion of water lost to the shallow aquifer system from infiltration impoundments, are summarized collectively as Managed Water Loss (MWL). Managed water losses include beneficial use. The percentage of CBM produced water included in the MWL varies by alternative and among sub-watersheds. These values are summarized in Appendix D.

Montana

This analysis assumed that CBM produced water would be managed in two ways: discharge to the surface, which was assumed to reach the main stem streams in each sub-watershed; and management using other options, which was assumed not to reach the main-stem streams. Under surface discharge, the analysis assumed that 20 percent of the volume would be lost to infiltration, evaporation, uptake by plants, and local beneficial uses. In the model, MWL would include impoundments, treatment and use, injection, and other industrial uses, such as in coal mining operations. The proportion of produced water discharged to the surface and the percentage of MWL vary by alternative and among the various sub-watersheds. These values are summarized in Appendix D.

4.2.3.2 Conveyance Loss

Conveyance loss includes evaporative and infiltration losses. Infiltration into soil typically comprises approximately 20 percent of precipitation in a watershed for arid and semi-arid regions (Stephens and Knowlton 1986). This analysis assumed that this value would represent loss in overland flow, and thus, was used as a minimum conveyance loss in the surface water model. The conveyance loss was applied to the proportion of CBM water discharged directly to the surface and to the proportion of CBM produced water discharged to infiltration impoundments that was assumed to resurface and contribute to existing surface flows. In addition, this analysis uses conveyance loss synonymously with “in-channel loss.” Higher rates of infiltration combined with some evaporative losses would result in a smaller fraction of the discharges of CBM produced water that would reach the main stems.

4.3 Assumptions

The following assumptions form the framework for analyzing the impacts in this document:

- Discharge of CBM produced water to surface drainages is assumed to result in a conveyance loss of 20 percent. This value is considerably lower than the values derived from studies of surface water losses in creek flows within several drainages of the Wyoming portion of the PRB (Meyer 2000, Applied Hydrology and Associates 2001a). The remaining 80 percent of the CBM produced water discharged to surface drainages is assumed to reach the main stem in each sub-watershed.

- Where produced water is discharged to infiltration impoundments designed to allow infiltration, 15 percent of the water would resurface and contribute to in-channel flow; the remainder would infiltrate into the shallow aquifer system.

- It is assumed that the sodium and salinity in water produced from CBM wells are the target constituents that control the usefulness of the water for crop irrigation. Irrigation is the primary beneficial use for the majority of water resources in the sub-watersheds expected to have the greatest potential for CBM development, especially in the Montana portion of the Powder River Basin. Sodium causes osmotic stress to plants and destroys the texture of clayey soils; these combined effects make sodium content, and especially SAR, a point of emphasis when impacts to water resources from CBM water are evaluated. The salinity of irrigation water, as expressed by EC, affects crop productivity. This analysis defined the irrigation season as the period from April 1 through October 31.

- The impact analysis did not consider changes in water quality that may occur as the CBM discharge flows overland toward the main stem streams or as it infiltrates to shallow groundwater systems and is discharged to surface flows. Results from monitoring water quality and flow from the tributary monitoring program suggest that CBM discharges tend to accumulate salts (EC) from the soils and alluvium as they flow down tributary channels and that SAR values decrease (Applied Hydrology and Associates 2001b). Thus, CBM discharges improve with respect to SAR but worsen with respect to EC between the discharge point and the receiving stream. Therefore, using the water quality of the CBM discharge provides a more conservative estimate of the impact on surface water of the main stems.

- The impact analysis did not consider values for individual constituents (sodium, magnesium, and calcium) in determining the resultant SAR values. This assumption is inherently conservative and is discussed in greater detail in Appendix B.

5.0 IMPACTS PROJECTED BY THE SURFACE WATER MODEL

The projected impacts of CBM development on surface water quality in each sub-watershed were derived with the use of four graphs, which are described below. The four graphs included in this document for each sub-watershed depict the preferred alternative, which for the Wyoming streams is Alternative 2A and for the Montana streams is Alternative E. The first graph plots ambient and projected EC for mean monthly and 7Q10 flows. The second graph plots ambient and projected SAR for mean monthly and 7Q10 flows. Both these graphs include lines showing the LRPL and MRPL to facilitate evaluation of the impacts. The next two graphs plot ambient and projected water quality for both EC and SAR in relation to the Ayers-Westcott EC-SAR threshold that represents no reduction in the rate of infiltration" as well as to the LRPL and MRPL. Water quality that meets the proposed EC and SAR limits as well as the Ayers-Westcott threshold should fall to the left of the proposed EC limit, below the proposed SAR limit and below and to the right of the diagonal line on the graphs. The first of these graphs plots ambient and projected EC and SAR for mean monthly and 7Q10 flows. The second plots the projected EC and SAR for incremental proportions of CBM discharge. The input parameters used in developing the graphs are summarized in Appendices C and D.

When considering the potential impacts to surface water resources discussed below for each sub-watershed under the various alternatives, the reader should be aware that the mass balance model used in this analysis is a tool for comparison of alternatives, and analysis of relative contributions of cumulative impacts. However, due to a lack of data regarding chemical transport relationships and conveyance loss it may not accurately predict likely impacts on resultant water quality (See Appendix E). Samples collected since the onset of CBM production in the Upper Belle Fourche River and Little Powder River sub-watersheds have not detected changes in ambient stream water quality which were predicted by the mass balance model, and actual impacts may be less then the mass balance model predicts. The magnitude of the model results can not be verified based upon actual measured water quality data. Adequate protection of existing uses and water quality standards can only be accomplished through direct monitoring of stream water quality to measure the effects of CBM discharge.

5.1 Wyoming Streams

5.1.1 Belle Fourche River

Results of the impact analysis in the Upper Belle Fourche River sub-watershed under each alternative are presented in Table 5-1. Potential impacts are discussed below.

5.1.1.1 Alternative 1

Under Alternative 1, the peak of water production in the Upper Belle Fourche River sub-watershed would occur in year 2006, when 7,630 wells would be producing at an average rate of 7.0 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Belle Fourche River sub-watershed during the peak year of CBM water production is about 49 cfs (35,479 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC values in the Upper Belle Fourche River currently exceed the MRPL and LRPL for EC during low-flow conditions. Mean monthly SAR values currently are less than the MRPL and LRPL for

SAR under similar flow conditions. After they mix, the resultant stream flow under low-flow conditions would consist almost entirely of CBM produced water. The resulting EC would decrease, whereas the SAR would increase from existing conditions. The existing 7Q10 flow is calculated as zero, so that the resulting water quality under these flow conditions would be represented by the quality of CBM produced water, if discharges were to occur during critical low flow periods. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Upper Belle Fourche River at Moorcroft, Wyoming, during all months of the year and during 7Q10 flow conditions would be adequate to meet the MRPL for both EC and SAR that WDEQ has adopted in its NPDES permitting process to be protective of downstream irrigation uses.
- LRPL: The LRPL for both EC and SAR also would be met under similar flow conditions.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates that there would be some reduction in infiltration during some months of the irrigation season (April, and July through October), as well as during 7Q10 flow conditions. Only a small fraction (10 percent) of the CBM discharge could occur without causing potential effects to infiltration during the low monthly flow.

5.1.1.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be less than under Alternative 1 primarily because of the increase in surface discharge and lowered use of infiltration and containment impoundments for water handling. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Belle Fourche River sub-watershed during the peak year of CBM water production is about 61 cfs (44,168 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Table 5-1
Impact Analysis for Surface Water of the Upper Belle Fourche River Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum mean monthly flow			Resulting Stream Water Quality at Minimum mean monthly flow			Existing Stream Water Quality at 7Q10 flow			Resulting Stream Water Quality at 7Q10 flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	10 (1)	2000 (1)	10 (2)	2500 (2)	2.3	6.8	2755	51	8.1	1051	0.0	--	--	49	8.2	970
2A	10 (1)	2000 (1)	10 (2)	2500 (2)				64	8.1	1034				62	8.2	970
2B	10 (1)	2000 (1)	10 (2)	2500 (2)				64	8.1	1034				62	8.2	970
3	10 (1)	2000 (1)	10 (2)	2500 (2)				37	8.1	1081				35	8.2	970

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.
(1) WDEQ limit applied to waters that flow downstream into South Dakota
(2) South Dakota's existing water quality standards.

After they have mixed, the resultant stream flow under low-flow conditions would consist almost entirely of CBM produced water. The resulting EC would decrease, whereas the SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-1 and 5-2 illustrate the months during the year under Alternative 2A when the existing stream water quality and resulting mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL adopted for water quality in the Upper Belle Fourche River sub-watershed. Under modeled conditions, the resulting water quality in the Belle Fourche River at Moorcroft, Wyoming, during all months of the year and during 7Q10 flow conditions would be adequate to meet the MRPL for both EC and SAR that WDEQ has adopted in its NPDES permitting process to be protective of downstream irrigation uses.
- LRPL: The LRPL for both EC and SAR also would be met under similar flow conditions.
- Ayers and Westcot diagram: Figure 5-3 illustrates the relationship between EC and SAR in the Belle Fourche River before and after the water mixes with discharges of CBM produced water. Irrigation with the mixed water indicates that there would be some reduction in infiltration during some months of the irrigation season, as well as during 7Q10 flow conditions. Figure 5-4 illustrates the relationship between EC and SAR in the Belle Fourche River after the water mixes with varying proportions of CBM produced water discharges under various stream flow conditions. Only a small fraction (10 percent) of the CBM discharge could occur without causing potential effects to infiltration during the low monthly flow.

Based on modeled results, impacts to the suitability for irrigation of the Upper Belle Fourche River from CBM development may occur. However, as noted previously, samples collected since the onset of CBM production in the Upper Belle Fourche River sub-watershed have not detected changes in ambient stream water quality which were predicted by the mass balance model, and actual impacts may be less then the mass balance model predicts. The magnitude of the model results can not be verified based upon actual measured water quality data. Adequate protection of existing uses and water quality standards can only be accomplished through direct monitoring of stream water quality to measure the effects of CBM discharge. In addition, discharge permits issued by the WDEQ will be the mechanism that will identify the appropriate mix of water handling methods to be employed to meet the standards. As a result, even though the model predicts impacts, ultimately those predicted impacts to the irrigation suitability of the Upper Belle Fourche River from CBM development in Wyoming under Alternatives 1 and 2A may not occur.

Figure 5-1 Stream EC Before and After Mixing-Upper Belle Fourche River Sub-Watershed

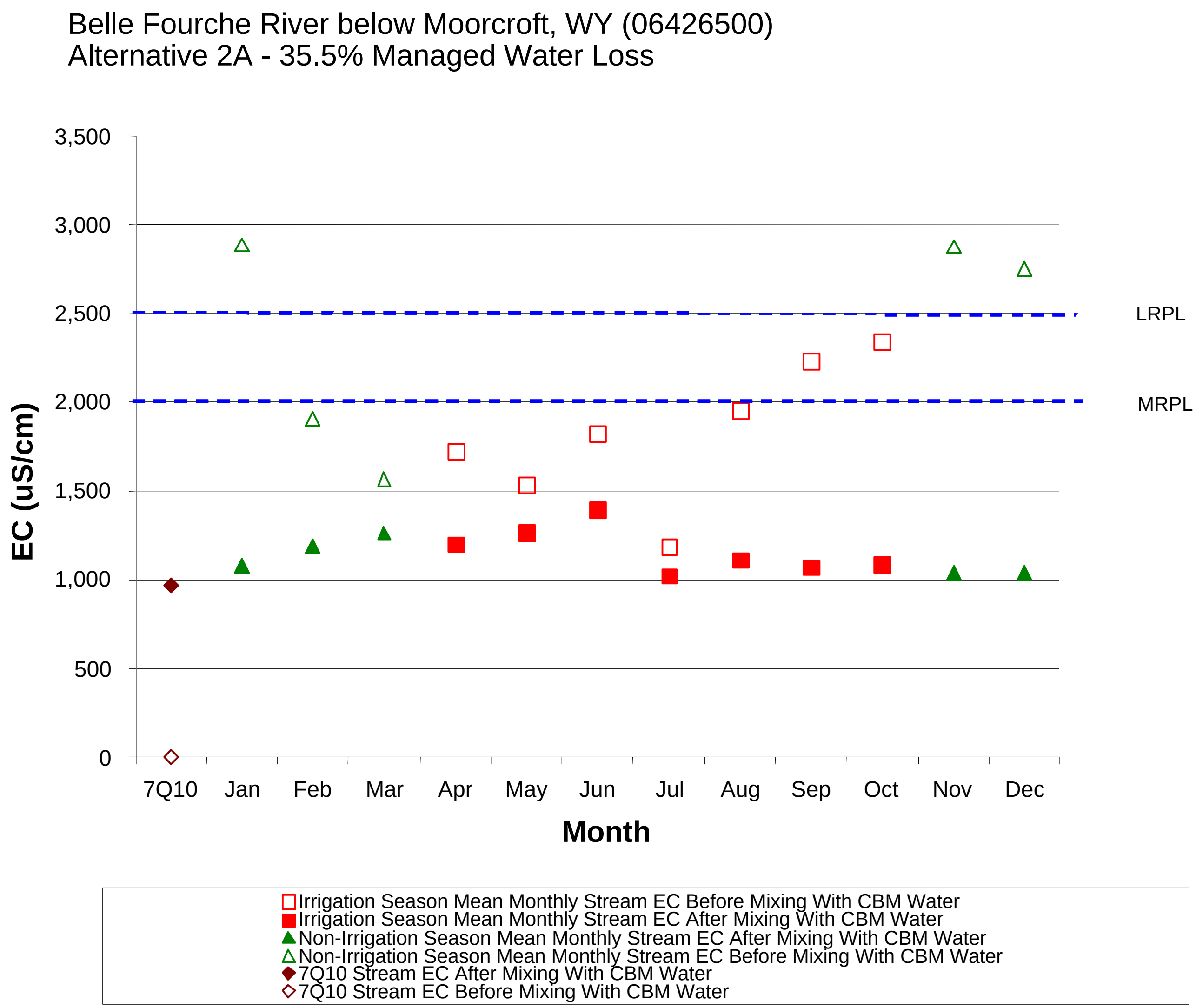


Figure 5-2 Stream SAR Before and After Mixing-Upper Belle Fourche River Sub-Watershed

Belle Fourche River below Moorcroft, WY (06426500)
Alternative 2A - 35.5% Managed Water Loss

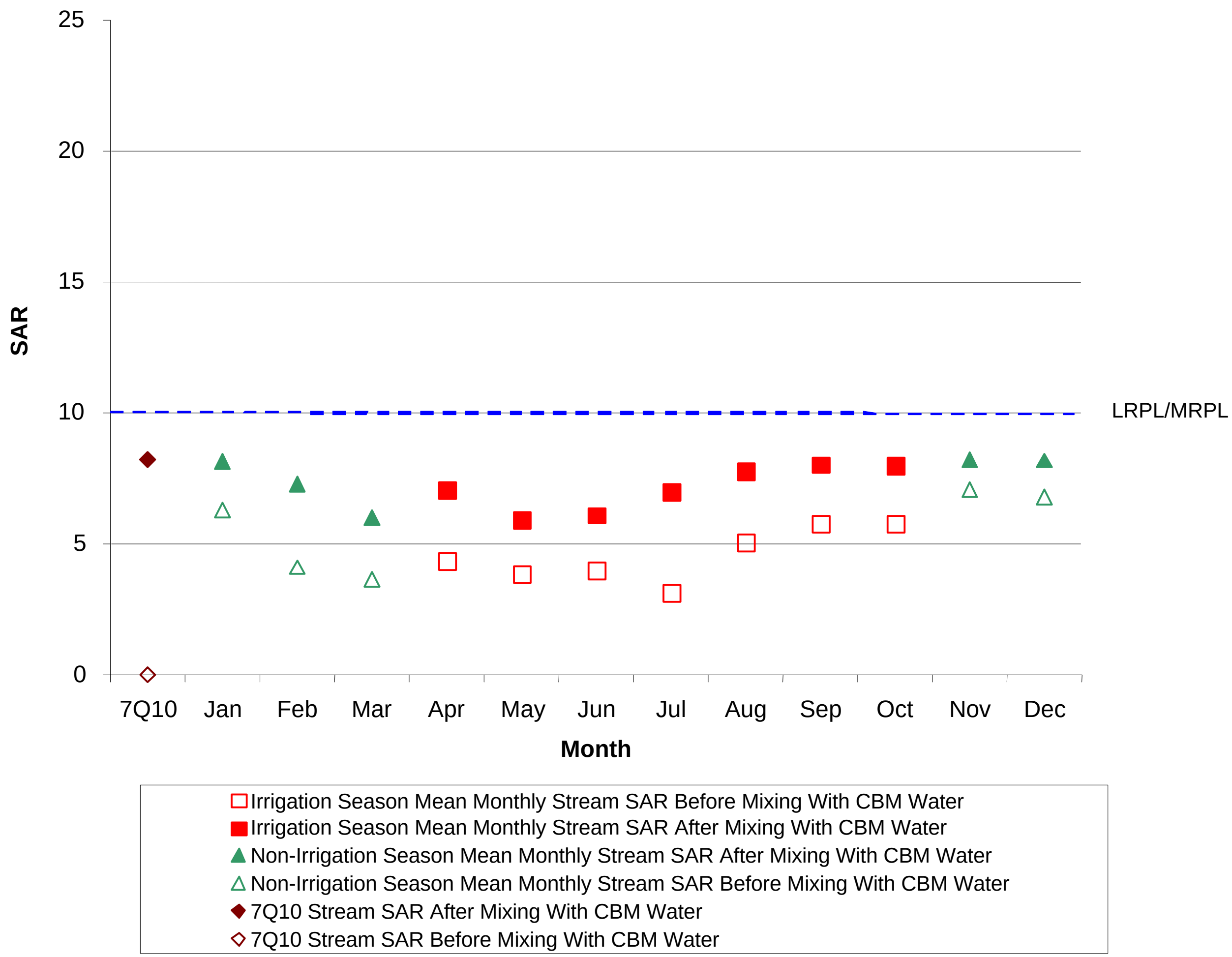


Figure 5-3 Irrigation Suitability Before and After Mixing – Upper Belle Fourche River Sub-Watershed

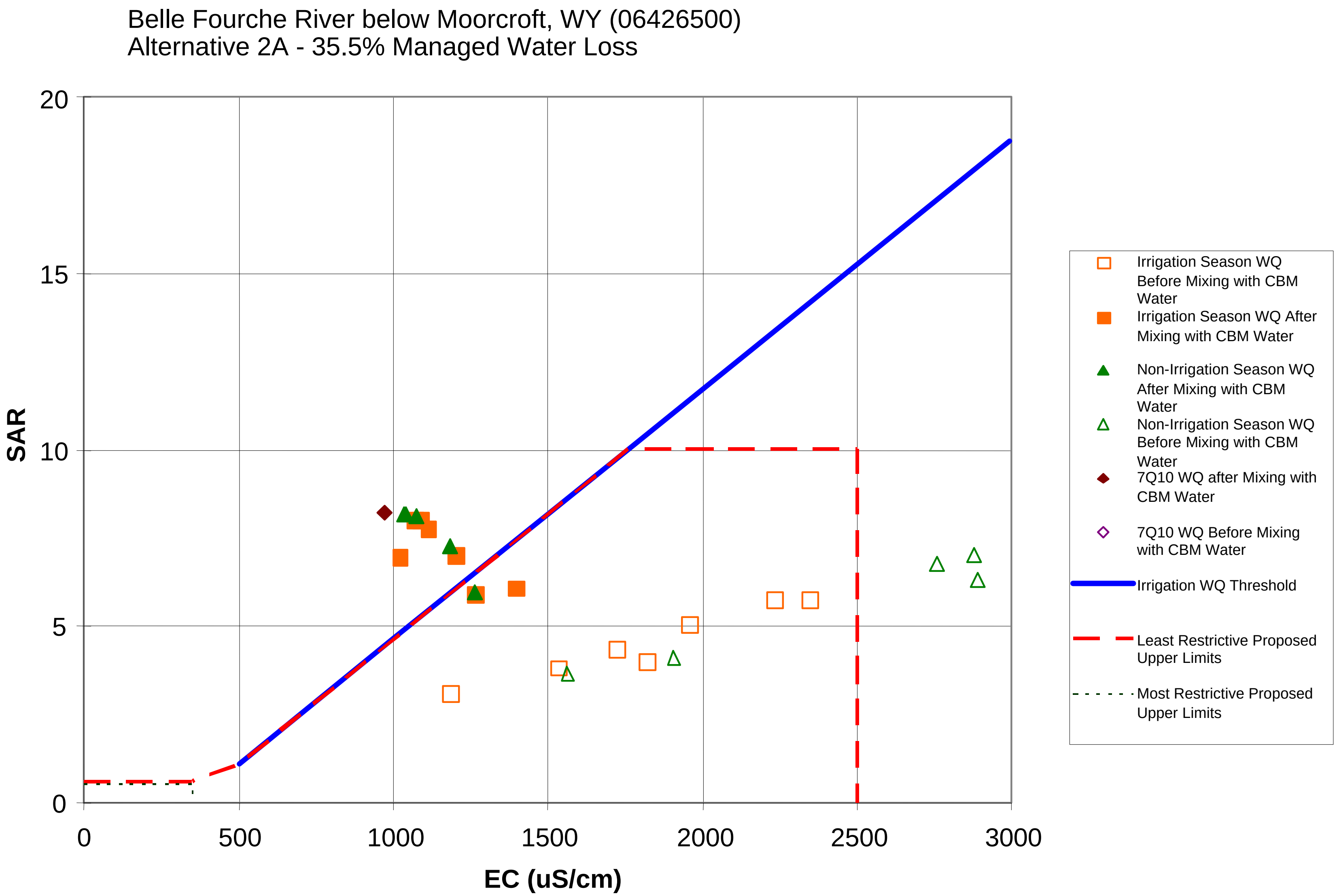
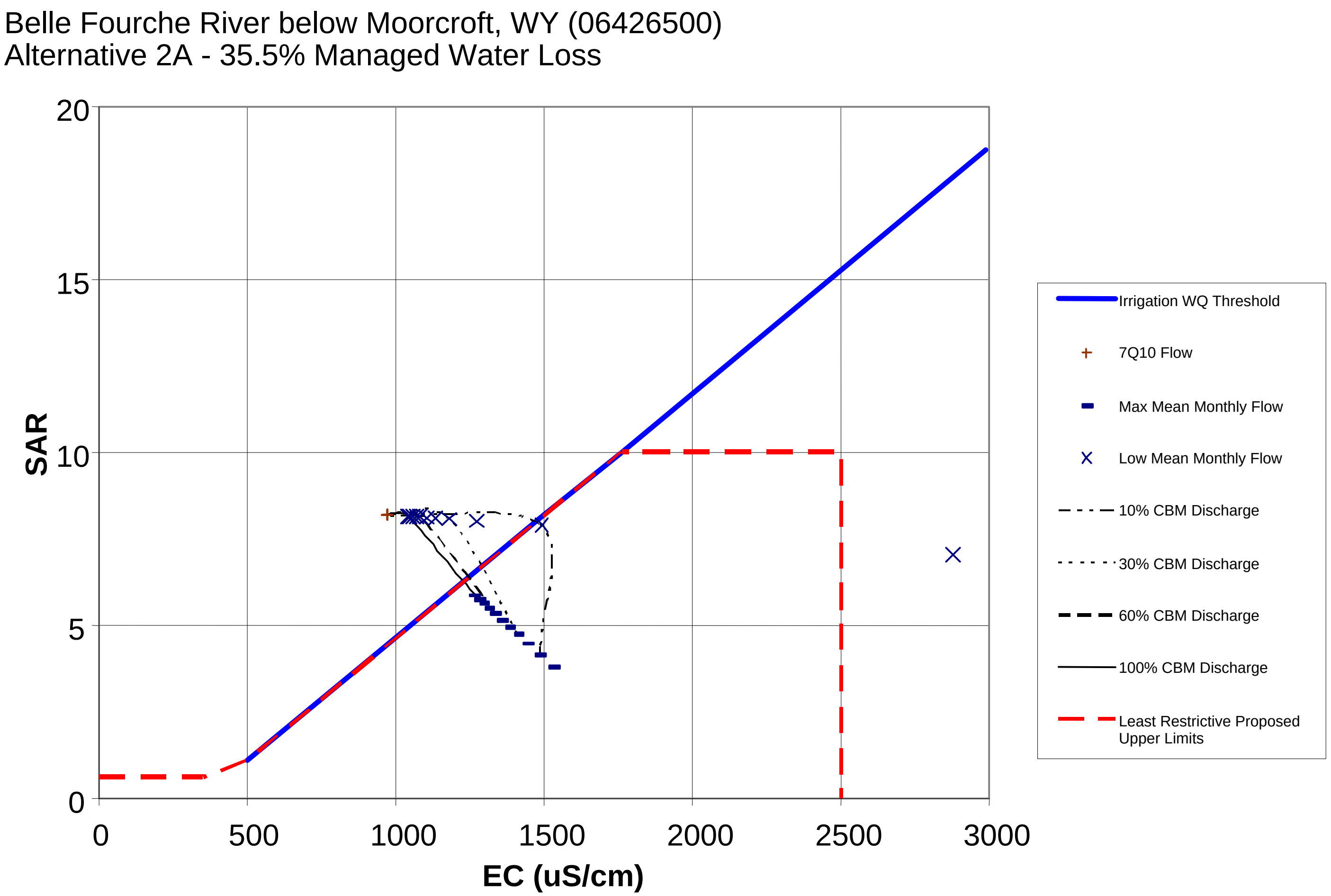


Figure 5-4 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Upper Belle Fourche River Sub-Watershed



5.1.1.3 Alternative 2B

There is no difference between Alternatives 2A and 2B that would affect the modeled output in the Upper Belle Fourche River sub-watershed. Thus, potential impacts described above for Alternative 2A would be the same under Alternative 2B.

5.1.1.4 Alternative 3

Under Alternative 3, the peak of water production in the Upper Belle Fourche River sub-watershed would occur in year 2005, when 6,160 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Belle Fourche River sub-watershed during the peak year of CBM water production is about 35 cfs (25,342 acre-feet per year). Impacts to surface water quality in the Upper Belle Fourche River sub-watershed would be similar to Alternative 1.

5.1.2 Cheyenne River

5.1.2.1 Antelope Creek

Results of the impact analysis in the Antelope Creek sub-watershed under each alternative are presented in Table 5-2. Potential impacts are discussed below.

5.1.2.1.1 Alternative 1

Under Alternative 1, the peak of water production in the Antelope Creek sub-watershed would occur in year 2004, when 925 wells would be producing at an average rate of 11.9 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Antelope Creek sub-watershed during the peak year of CBM water production is about 12 cfs (8,689 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC values in Antelope Creek currently exceed the MRPL, but are less than the LRPL during low-flow conditions. Mean monthly SAR values currently are less than the MRPL and LRPL under similar flow conditions. After they mix, the resultant stream flow under low-flow conditions would consist almost entirely of CBM produced water. The resulting EC would decrease, whereas the SAR would increase from existing conditions. The existing 7Q10 flow could not be computed because of a lack of data; therefore, the resultant water quality under these flow conditions is assumed to be represented by the quality of CBM produced water if discharges were to occur during critical low-flow periods. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in Antelope Creek near Teckla, Wyoming, during all months of the year and during 7Q10 flow conditions would be adequate to meet the MRPL for both EC and SAR that WDEQ has adopted in its NPDES permitting process to be protective of downstream irrigation uses.
- LRPL: The LRPL for both EC and SAR also would be met under similar flow conditions.

- Ayers and Westcot diagram: Irrigation with the mixed water indicates some effects to infiltration, primarily during the lowest flow months of September through February, and during 7Q10 flow conditions. During the low monthly flow, only a small fraction (less than 10 percent) of the CBM discharge could occur without causing potential effects to infiltration.

Table 5-2
Surface Water Impact Analysis of the Antelope Creek Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum mean monthly flow			Resulting Stream Water Quality at Minimum mean monthly flow			Existing Stream Water Quality at 7Q10 flow			Resulting Stream Water Quality at 7Q10 flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	10 (1)	2000 (1)	10 (2)	2500 (2)	0.2	2.6	2354	12	7.0	924	NC	--	--	12	7.1	905
2A	10 (1)	2000 (1)	10 (2)	2500 (2)				13	7.0	923				13	7.1	905
2B	10 (1)	2000 (1)	10 (2)	2500 (2)				13	7.0	923				13	7.1	905
3	10 (1)	2000 (1)	10 (2)	2500 (2)				7	7.0	937				7	7.1	905

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
NC=Not calculated based on insufficient record
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.
(1) WDEQ limit applied to waters that flow downstream into South Dakota
(2) South Dakota's existing water quality standards

5.1.2.1.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be less than under Alternative 1, primarily because of the increase in surface discharge and lowered use of infiltration and containment impoundments. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Antelope Creek sub-watershed during the peak year of CBM water production is about 13 cfs (9,413 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After they mix, the resultant stream flow under low-flow conditions would consist almost entirely of CBM produced water. The resulting EC would decrease, whereas the SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-5 and 5-6 illustrate the months during the year under Alternative 2A when the existing stream water quality and resultant mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL adopted for water quality in the Antelope Creek sub-watershed. Under modeled conditions, the resultant water quality in Antelope Creek near Teckla, Wyoming, during all months of the year and during 7Q10 flow conditions would be adequate to meet the MRPL for both EC and SAR that WDEQ has adopted in its NPDES permitting process to be protective of downstream irrigation uses.
- LRPL: The LRPL for both EC and SAR also would be met under similar flow conditions.
- Ayers and Westcot diagram: Figure 5-7 illustrates the relationship between EC and SAR in Antelope Creek before and after the water mixes with discharges of CBM produced water. Irrigation with the mixed water indicates some effects to infiltration, primarily during the lowest flow months of September through February, and during 7Q10 flow conditions. Figure 5-8 illustrates the relationship between EC and SAR in Antelope Creek after mixing with varying proportions of CBM produced water discharges under various stream flow conditions. During the low monthly flow, only a small fraction (less than 10 percent) of the CBM discharge could occur without causing potential effects to infiltration.

Based on modeled results, impacts to the suitability for irrigation of Antelope Creek from CBM development may occur. However, as noted previously, samples collected since the onset of CBM production in the Upper Belle Fourche River and Little Powder River sub-watersheds have not detected changes in ambient stream water quality which were predicted by the mass balance model, and actual impacts may be less then the mass balance model predicts. The magnitude of the model results can not be verified based upon actual measured water quality data. Adequate protection of existing uses and water quality standards can only be accomplished through direct monitoring of stream water quality to measure the effects of CBM discharge. In addition, discharge permits issued by the WDEQ will be the mechanism that will identify the appropriate mix of water handling methods to be employed to meet the standards. As a result, even though the model predicts impacts, ultimately those predicted impacts to the irrigation suitability of Antelope Creek from CBM development in Wyoming under Alternatives 1 and 2A may not occur.

Figure 5-5 Stream EC Before and After Mixing-Antelope Creek Sub-Watershed

Antelope Creek near Teckla, WY (06364700)
Alternative 2A - 35.5% Managed Water Loss

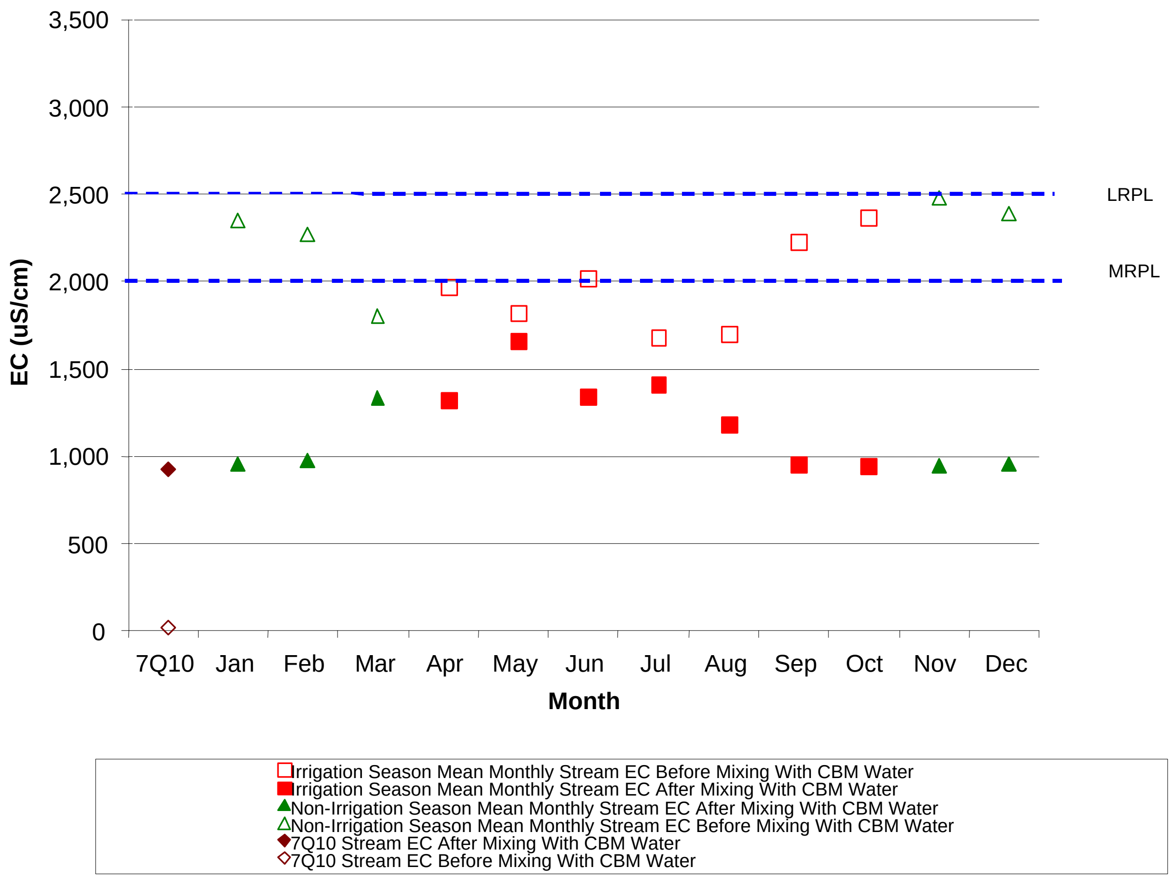


Figure 5-6 Stream SAR Before and After Mixing- Antelope Creek Sub-Watershed

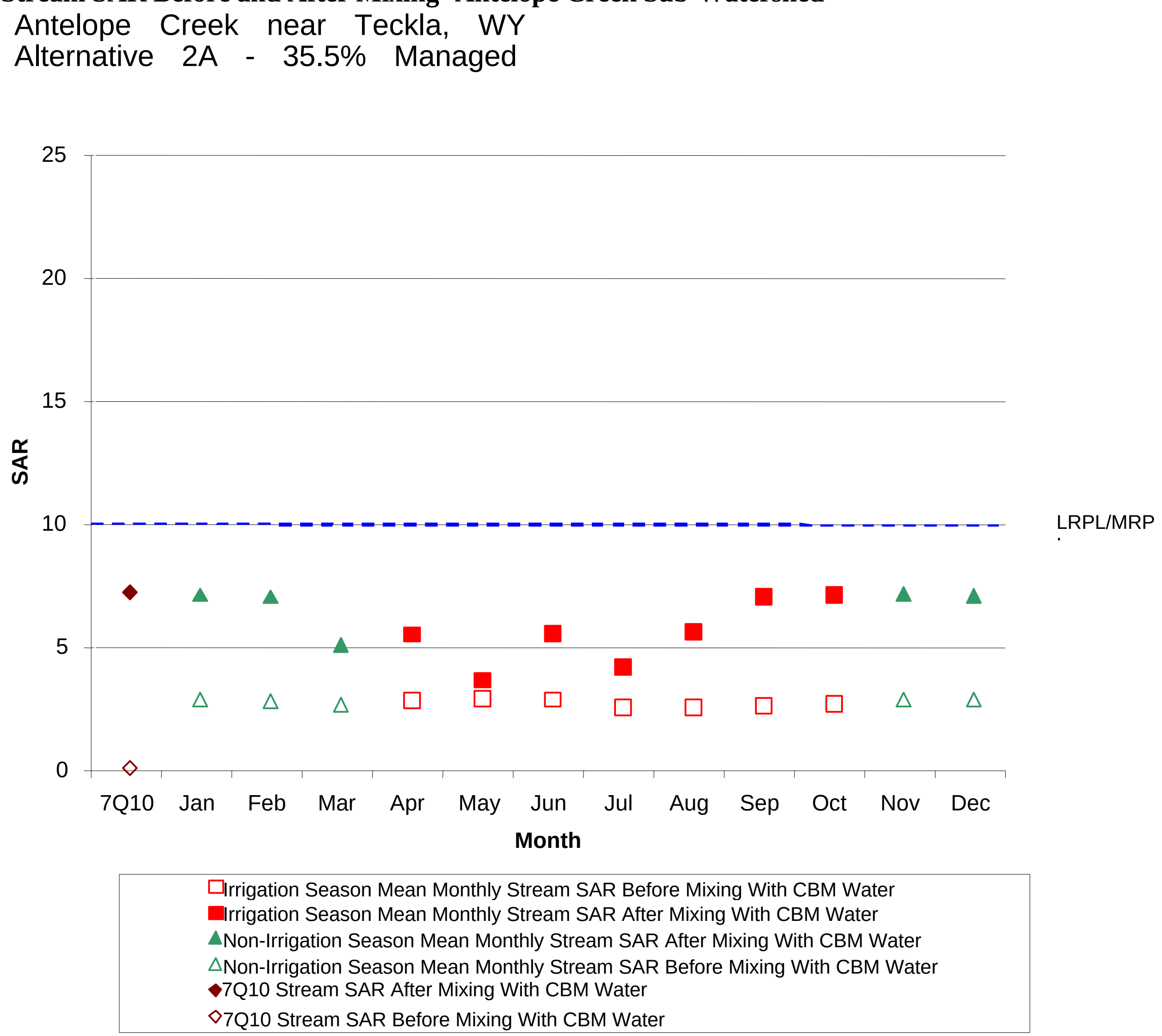


Figure 5-7 Irrigation Suitability Before and After Mixing – Antelope Creek Sub-Watershed

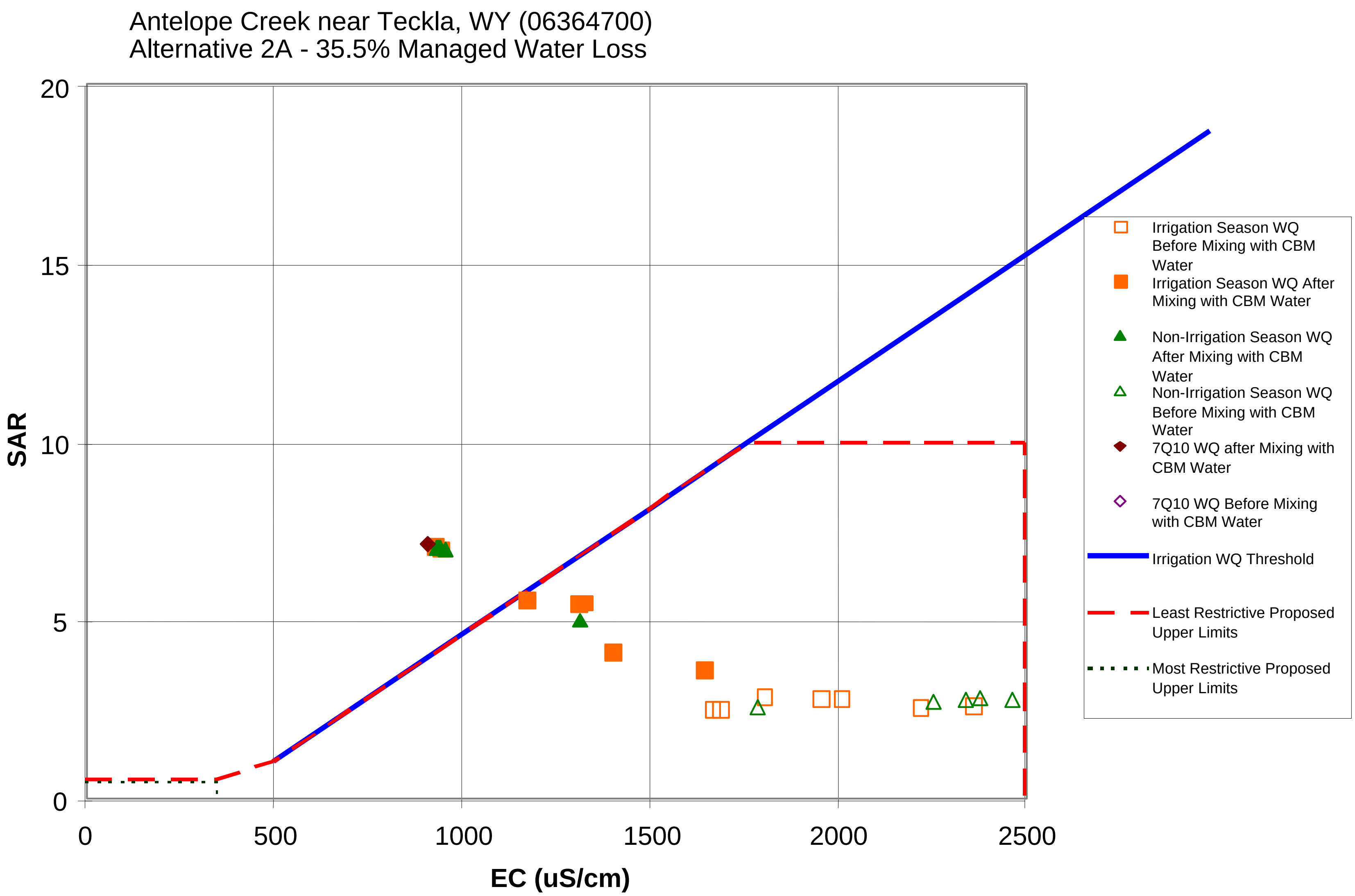
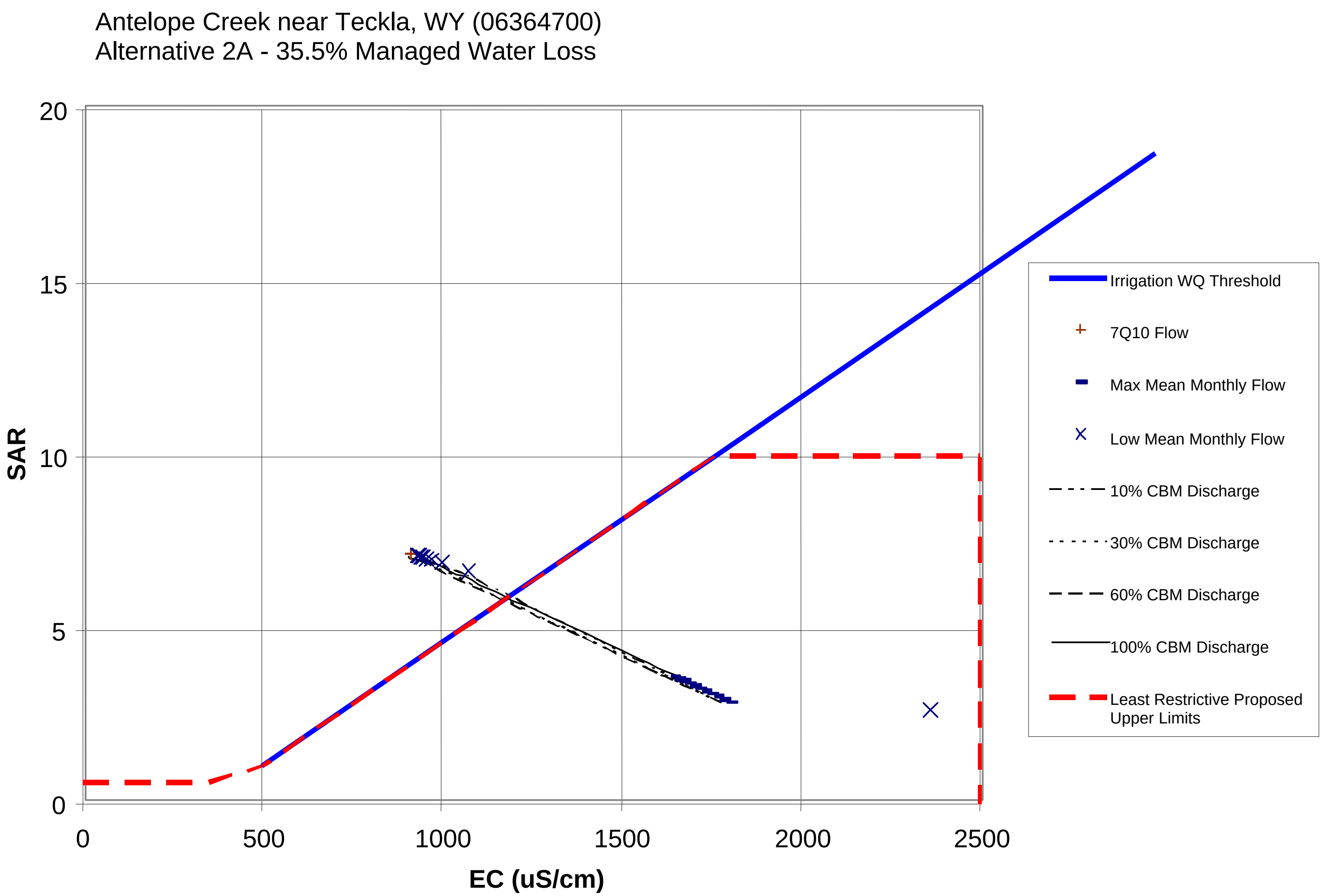


Figure 5-8 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Antelope Creek Sub-Watershed



5.1.2.1.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because active treatment would be implemented. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Antelope Creek sub-watershed during the peak year of CBM water production is about 12 cfs (8,689 acre-feet per year). Impacts to surface water quality in the Antelope Creek sub-watershed would be similar to Alternative 1. Additional water would be available to support beneficial use because of the proportion of water to undergo active treatment.

5.1.2.1.4 Alternative 3

Under Alternative 3, the peak of water production in the Antelope Creek sub-watershed would occur in year 2005, when 561 wells would be producing at an average rate of 11.9 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Antelope Creek sub-watershed during the peak year of CBM water production is about 7 cfs (5,068 acre-feet per year). Impacts to surface water quality in the Antelope Creek sub-watershed would be similar to Alternative 1.

5.1.2.2 Cheyenne River

The impact analysis of surface water in the Upper Cheyenne River sub-watershed incorporates the discharges of CBM produced water from the Antelope Creek sub-watershed under each of the alternatives to predict water quality conditions at the USGS gauging station on the Cheyenne River at Riverview, Wyoming.

Results of the impact analysis in the Upper Cheyenne River sub-watershed under each alternative are presented in Table 5-3. Potential impacts are discussed below.

5.1.2.2.1 Alternative 1

Under Alternative 1, the peak of water production in the Upper Cheyenne River sub-watershed would occur in year 2003, when 1,471 wells would be producing at an average rate of 11.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Cheyenne River sub-watershed during the peak year of CBM water production is about 18 cfs (13,033 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC values in the Upper Cheyenne River currently exceed the MRPL and LRPL during low-flow conditions. Mean monthly SAR values currently are less than the MRPL and LRPL under similar flow conditions. After they mix, the resulting stream flow under low-flow conditions would consist almost entirely of CBM produced water. Stream water quality would improve with the addition of CBM produced water. The resulting EC and SAR would decrease from existing conditions. The existing 7Q10 flow could not be computed because of a lack of data; however, the 7Q10 flow is zero calculated at the USGS station on the Cheyenne River at Edgemont, South Dakota; therefore, it is assumed that the resultant water quality under these flow conditions at the station in Riverview, Wyoming, would be represented by the quality of CBM produced water if discharges were to occur during critical low-flow periods. The resultant stream water quality can be compared with the following criteria:

Table 5-3
Surface Water Impact Analysis of the Upper Cheyenne River Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum mean monthly flow			Resulting Stream Water Quality at Minimum mean monthly flow			Existing Stream Water Quality at 7Q10 flow			Resulting Stream Water Quality at 7Q10 flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	10 (1)	2000 (1)	10 (2)	2500 (2)	0.4	8.7	4127	18	6.9	881	NC	--	--	18	6.9	806
2A	10 (1)	2000 (1)	10 (2)	2500 (2)				19	6.9	876				19	6.9	806
2B	10 (1)	2000 (1)	10 (2)	2500 (2)				19	6.9	877				19	6.9	806
3	10 (1)	2000 (1)	10 (2)	2500 (2)				12	6.9	896				12	6.9	806

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
NC=Not calculated based on insufficient record
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.
(1) WDEQ limit applied to waters that flow downstream into South Dakota
(2) South Dakota's existing water quality standards

- MRPL: Under modeled conditions, with the exception of during the highest flow months of September through December, and during 7Q10 flow conditions, the resultant water quality in the Upper Cheyenne River near Riverview, Wyoming would be adequate to meet the MRPL for EC that the WDEQ has adopted in their NPDES permitting process to be protective of downstream irrigation uses. The resultant SAR would be adequate to meet the MRPL during all months.
- LRPL: With the exception during October and November, the LRPL for EC would be met under similar flow conditions. The LRPL for SAR would be met during all months.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates some effects to infiltration during the irrigation season, primarily during low flow in April, and during 7Q10 flow conditions. During the low monthly flow, only a small fraction (10 percent) of the CBM discharge could occur without causing potential effects to infiltration.

5.1.2.2.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be less than under Alternative 1, primarily due to the increase in surface discharge and less use of infiltration and containment impoundments. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Cheyenne River sub-watershed during the peak year of CBM water production is about 19 cfs (13,757 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Following mixing, the resultant stream flow under low flow conditions would consist almost entirely of CBM produced water. Stream water quality would improve with the addition of CBM produced water. The resultant EC and SAR would decrease from existing conditions. The resultant stream water quality can be compared to the following criteria:

- MRPL: Figures 5-9 and 5-10 illustrate the months during the year under Alternative 2A when the existing stream water quality and resultant mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL adopted for water quality in the Upper Cheyenne River sub-watershed. Under modeled conditions, the resultant water quality in the Upper Cheyenne River near Riverview, Wyoming, would be adequate to meet the MRPL for EC that WDEQ has adopted in its NPDES permitting process to be protective of downstream irrigation uses. The exception would occur during the highest flow months of September through December and during 7Q10 flow conditions. The resulting SAR would be adequate to meet the MRPL during all months.
- LRPL: With the exception during October and November, the LRPL for EC would be met under similar flow conditions. The LRPL for SAR could be met during all months.
- Ayers and Westcot diagram: Figure 5-11 illustrates the relationship between EC and SAR in the Upper Cheyenne River before and after the water mixes with discharges of CBM produced water. Irrigation with the mixed water indicates some effects to infiltration during the irrigation season, primarily during low flow in April and during 7Q10 flow conditions. Figure 5-12 illustrates the relationship between EC and SAR in the Upper Cheyenne River after the water mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. During the low monthly flow, only a small fraction (10 percent) of the CBM discharge could occur without causing potential effects to infiltration.

Based on modeled results, impacts to the suitability for irrigation of the Upper Cheyenne River from CBM development may occur. However, as noted previously, samples collected since the onset of CBM production in the Upper Belle Fourche River and Little Powder River sub-watersheds have not detected changes in ambient stream water quality which were predicted by the mass balance model, and actual impacts may be less then the mass balance model predicts. The magnitude of the model results can not be verified based upon actual measured water quality data. Adequate protection of existing uses and water quality standards can only be accomplished through direct monitoring of stream water quality to measure the effects of CBM discharge. In addition, discharge permits issued by the WDEQ will be the mechanism that will identify the appropriate mix of water handling methods to be employed to meet the standards. As a result, even though the model predicts impacts, ultimately those predicted impacts to the irrigation suitability of the Upper Cheyenne River from CBM development in Wyoming under Alternatives 1 and 2A may not occur.

Figure 5-9 Stream EC Before and After Mixing- the Upper Cheyenne River Sub-Watershed

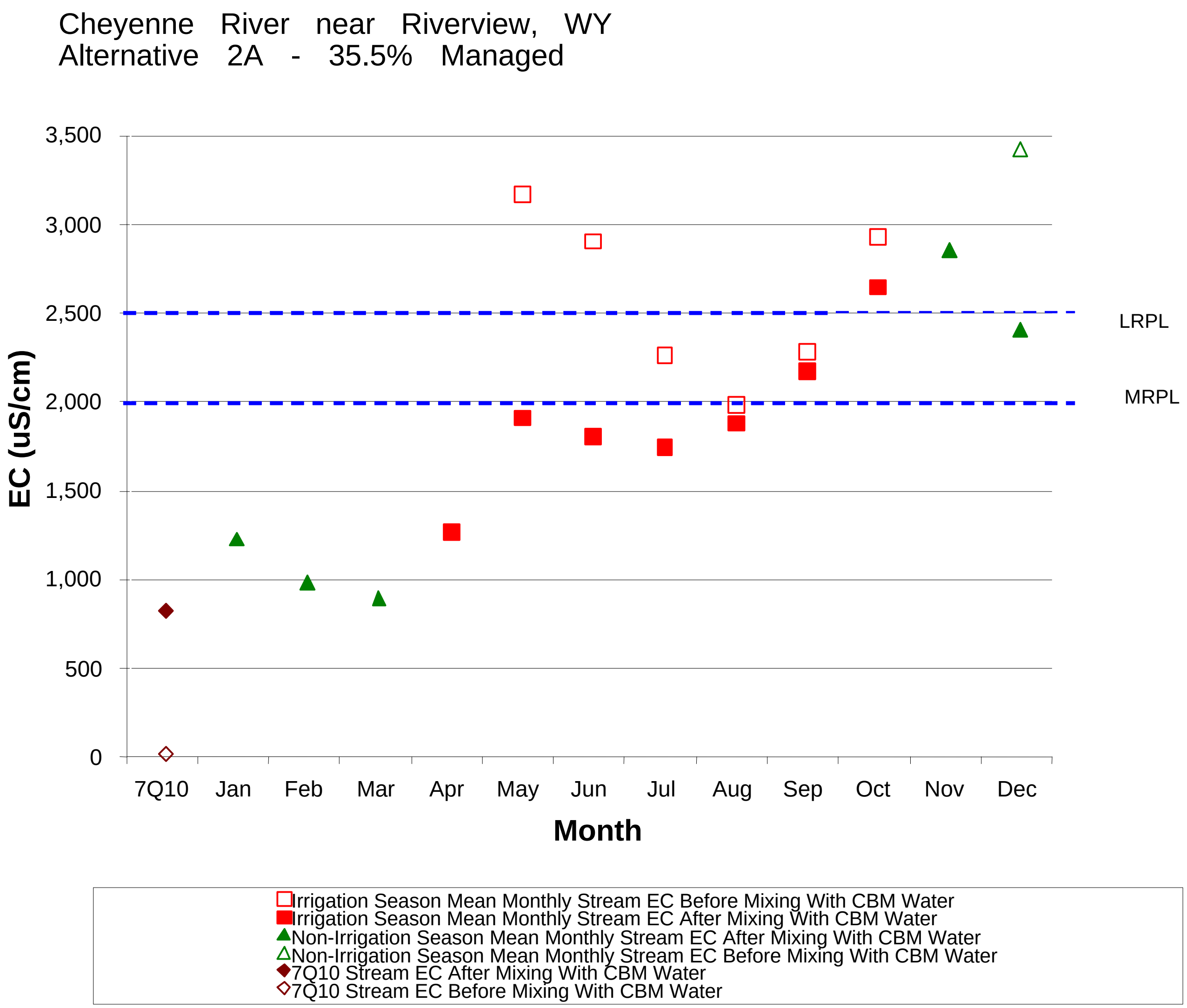


Figure 5-10 Stream SAR Before and After Mixing- the Upper Cheyenne River Sub-Watershed

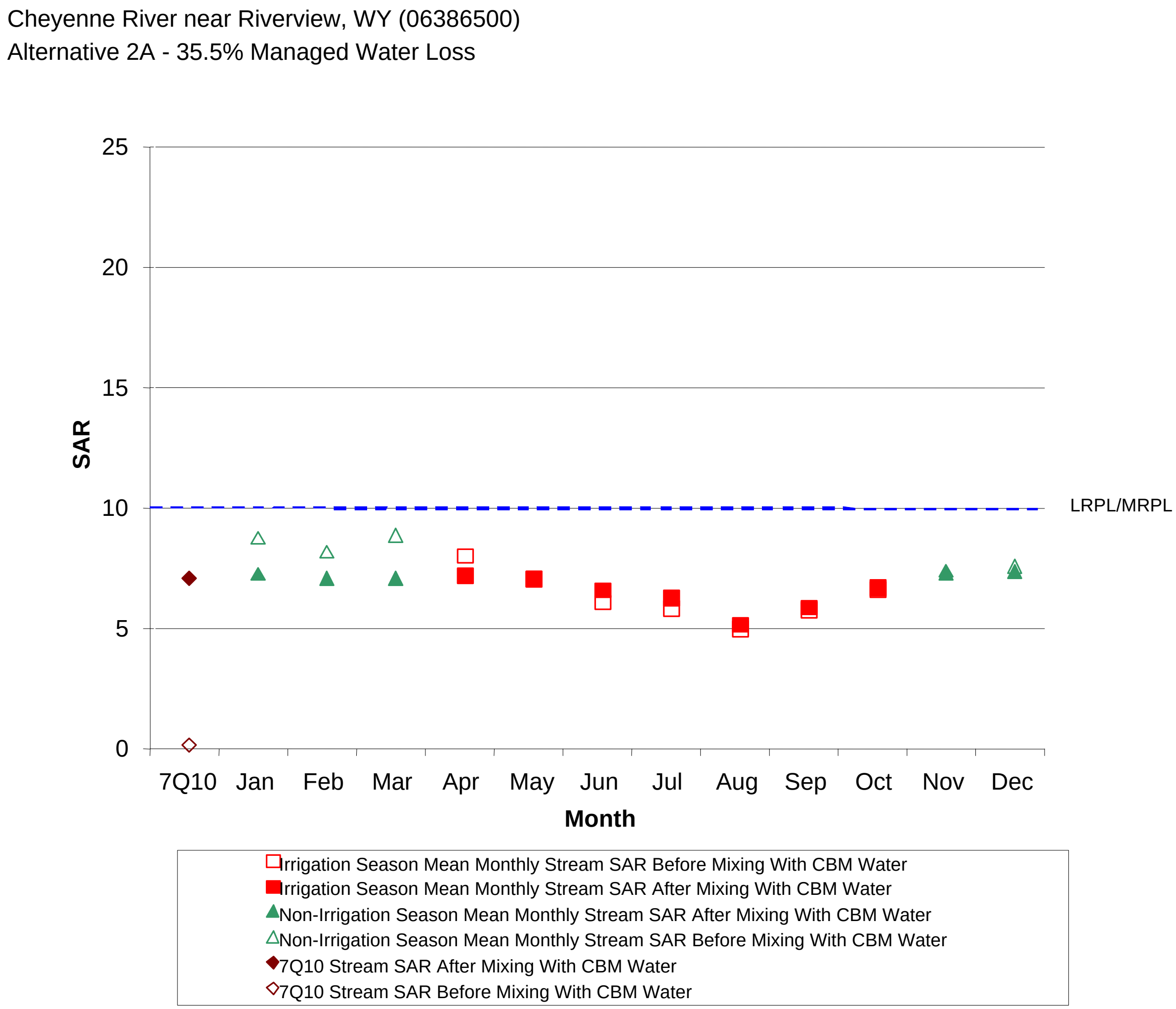


Figure 5-11 Irrigation Suitability Before and After Mixing – the Upper Cheyenne River Sub-Watershed

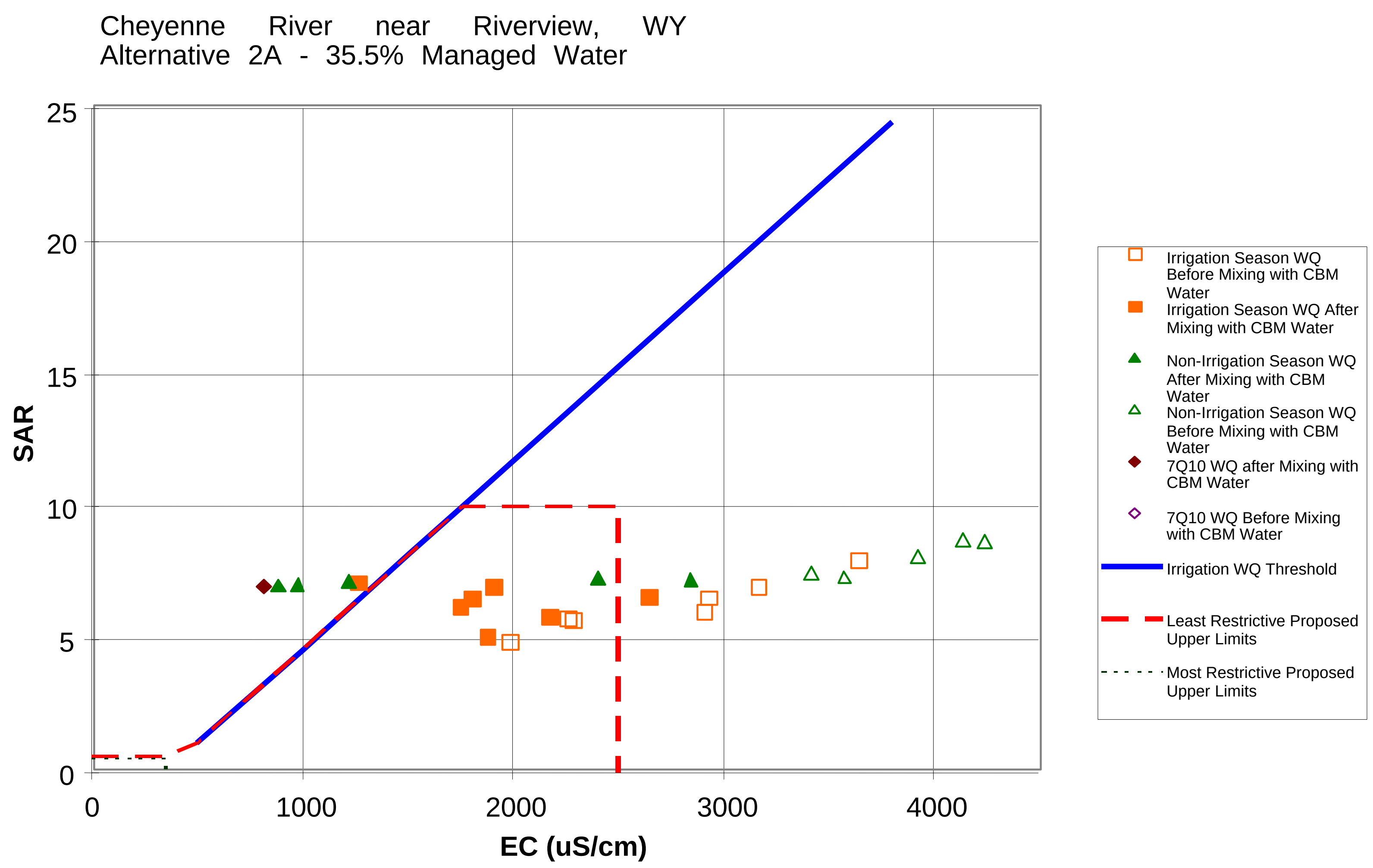
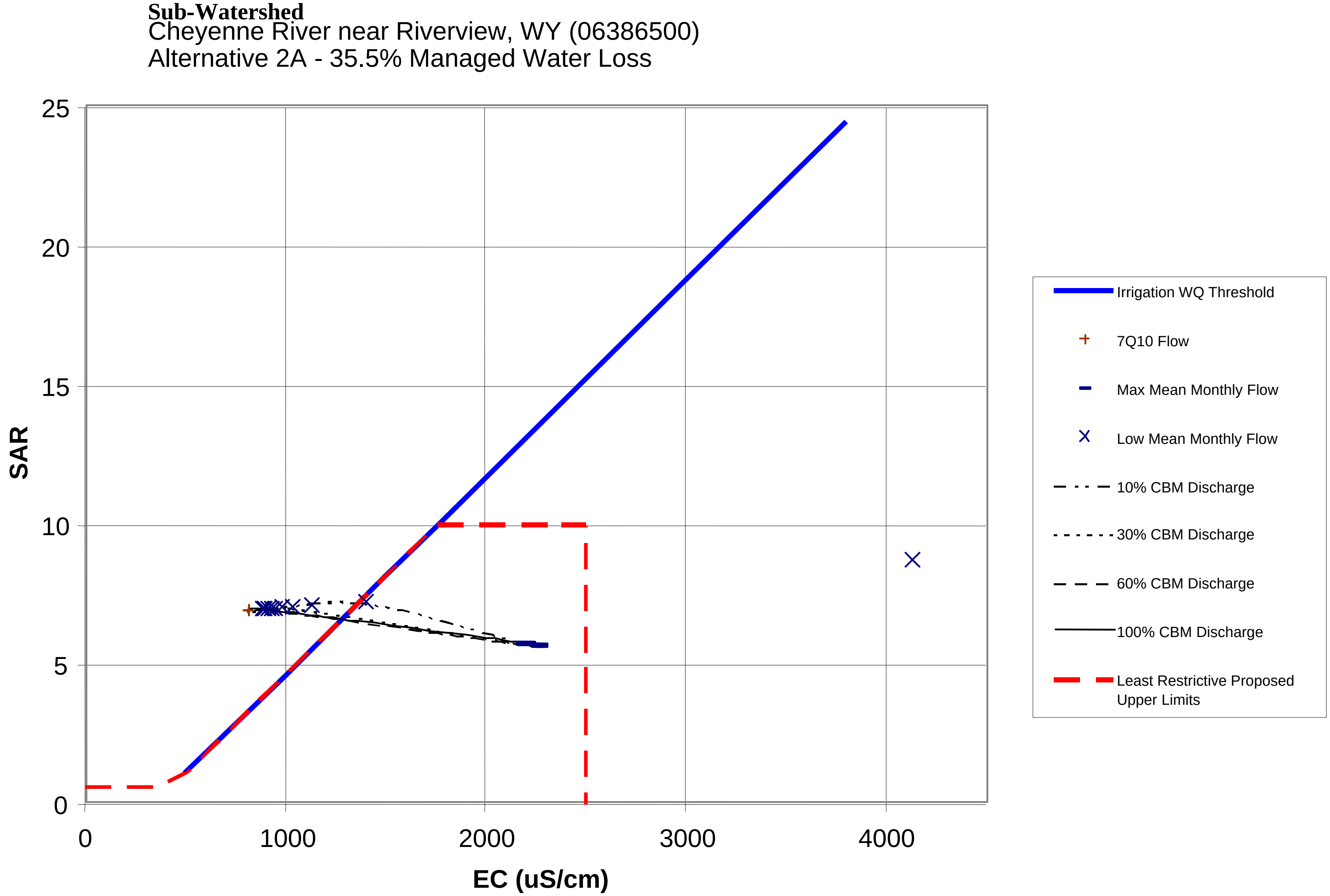


Figure 5-12 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – the Upper Cheyenne River Sub-Watershed



5.1.2.2.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in surface discharge and lowered use of infiltration and containment impoundments. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Cheyenne River sub-watershed during the peak year of CBM water production is about 18 cfs (13,033 acre-feet per year). Impacts to surface water quality would be similar to Alternative 1. Additional water would be available to support beneficial use because of the proportion of water to undergo active treatment.

5.1.2.2.4 Alternative 3

Under Alternative 3, the peak of water production in the Upper Cheyenne River sub-watershed would occur in Year 2003, when 1,030 wells would be producing at an average rate of 11.0 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Cheyenne River sub-watershed during the peak year of CBM water production is about 12 cfs (8,689 acre-feet per year). A comparison of the resultant mixed water quality with the Ayers-Westcot line indicates no effects to infiltration except for during 7Q10 flow conditions. Under Alternative 3, the resultant EC would not be adequate to meet the LRPL during several months of the irrigation season as well as during 7Q10 flow.

5.1.3 Upper Powder River

Results of the impact analysis in the Upper Powder River sub-watershed under each alternative are presented in Table 5-4. Potential impacts are discussed below.

Table 5-4
Surface Water Impact Analysis of the Upper Powder River Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	2.0	1000	10	3200	75	7.8	3400	211	15.3	2606	0.0	--	--	135	19.5	2163
2A	2.0	1000	10	3200				144	13.4	2812				68	19.5	2163
2B	2.0	1000	10	3200				138	13.1	2837				63	19.5	2163
3	2.0	1000	10	3200				121	12.2	2934				46	19.5	2163

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.1.3.1 Alternative 1

Under Alternative 1, the peak of water production in the Upper Powder River sub-watershed would occur in year 2006, when 15,822 wells would be producing at an average rate of 6.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Powder River sub-watershed during the peak year of CBM water production is about 135 cfs (97,749 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC values in the Upper Powder River currently exceed the MRPL and LRPL under low-flow conditions. Mean monthly SAR values currently exceed the MRPL, but are less than the LRPL under similar flow conditions. After the water mixes, the resultant stream flow under low-flow conditions would nearly triple from natural stream flow. The resultant EC would decrease, whereas the SAR would increase from existing conditions. The existing 7Q10 flow is calculated as zero; therefore, it is assumed that the resulting water quality under these flow conditions would be represented by the quality of CBM produced water if discharges were to occur during critical low flow periods. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Upper Powder River sub-watershed at Arvada, Wyoming, would not be adequate to meet the MRPL for EC and SAR at any time if it should be determined that the MRPL and LRPL criteria are protective of downstream irrigation uses.
- LRPL: Under modeled conditions, the resultant water quality would be adequate to meet the LRPL for EC during all months as well as during 7Q10 flow conditions. The resulting water quality would not be adequate to meet the LRPL for SAR during the irrigation months of July through October or during 7Q10 flow conditions.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates no effects to infiltration during the irrigation months; however, some reduction in infiltration would be likely during 7Q10 flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

5.1.3.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1 primarily because of the increase in infiltration impoundments and lowered surface discharge. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Powder River sub-watershed during the peak year of CBM water production is about 68 cfs (49,237 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After the water mixes, the resultant stream flow under low-flow conditions would nearly triple from natural stream flow. The resultant EC would decrease, whereas the SAR would increase from existing conditions. The resulting stream water quality can be compared with the following criteria:

- MRPL: Figures 5-13 and 5-14 illustrate the months during the year under Alternative 2A when the existing stream water quality and resultant mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL or LRPL adopted for water quality in the Upper Powder River sub-watershed. Under modeled conditions, the resultant water quality in the Upper Powder River at Arvada, Wyoming, would not be adequate to meet the MRPL for EC and SAR at any time if it should be determined that the MRPL and LRPL criteria are protective of downstream irrigation uses.
- LRPL: Under modeled conditions, the resultant water quality would be adequate to meet the LRPL for EC during all months as well as during 7Q10 flow conditions. The resulting water quality would not be adequate to meet the LRPL for SAR during the irrigation months of August through October or during 7Q10 flow conditions.
- Ayers and Westcot diagram: Figure 5-15 illustrates the relationship between EC and SAR in the Upper Powder River before and after the river mixes with discharges of CBM produced water. Irrigation with the mixed water indicates no effects to infiltration during the irrigation months; however, some reduction in infiltration would be likely during 7Q10 flow conditions. Figure 5-16 illustrates the relationship between EC and SAR in the Upper Powder River after the water mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without affecting infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Based on modeled results, under certain flow conditions, impacts to irrigated agriculture in the Upper Powder River sub-watershed from CBM development in Wyoming under Alternative 2A may occur. Although the resultant impacts fall outside the boundaries of the LRPL during some months, BLM recognizes the uncertainty concerning the determination of water quality standards for EC and SAR. If a standard at the low end of the range of proposed values is selected, additional mitigation may be necessary for CBM discharges to this sub-watershed to occur. Potential mitigation measures that could be implemented in order to meet the ultimate regulatory standards for EC and SAR once those standards have been identified include CBM produced water storage during the irrigation months and surface discharge during the non-irrigation months. In addition, discharge permits issued by the WDEQ will be the mechanism that will identify the appropriate mix of water handling methods to be employed to meet the standards. As a result, even though the model predicts impacts, ultimately those predicted impacts to the irrigation suitability of the Upper Powder River from CBM development in Wyoming under Alternatives 1 and 2A may not occur.

Figure 5-13 Stream EC Before and After Mixing-Upper Powder River Sub-Watershed

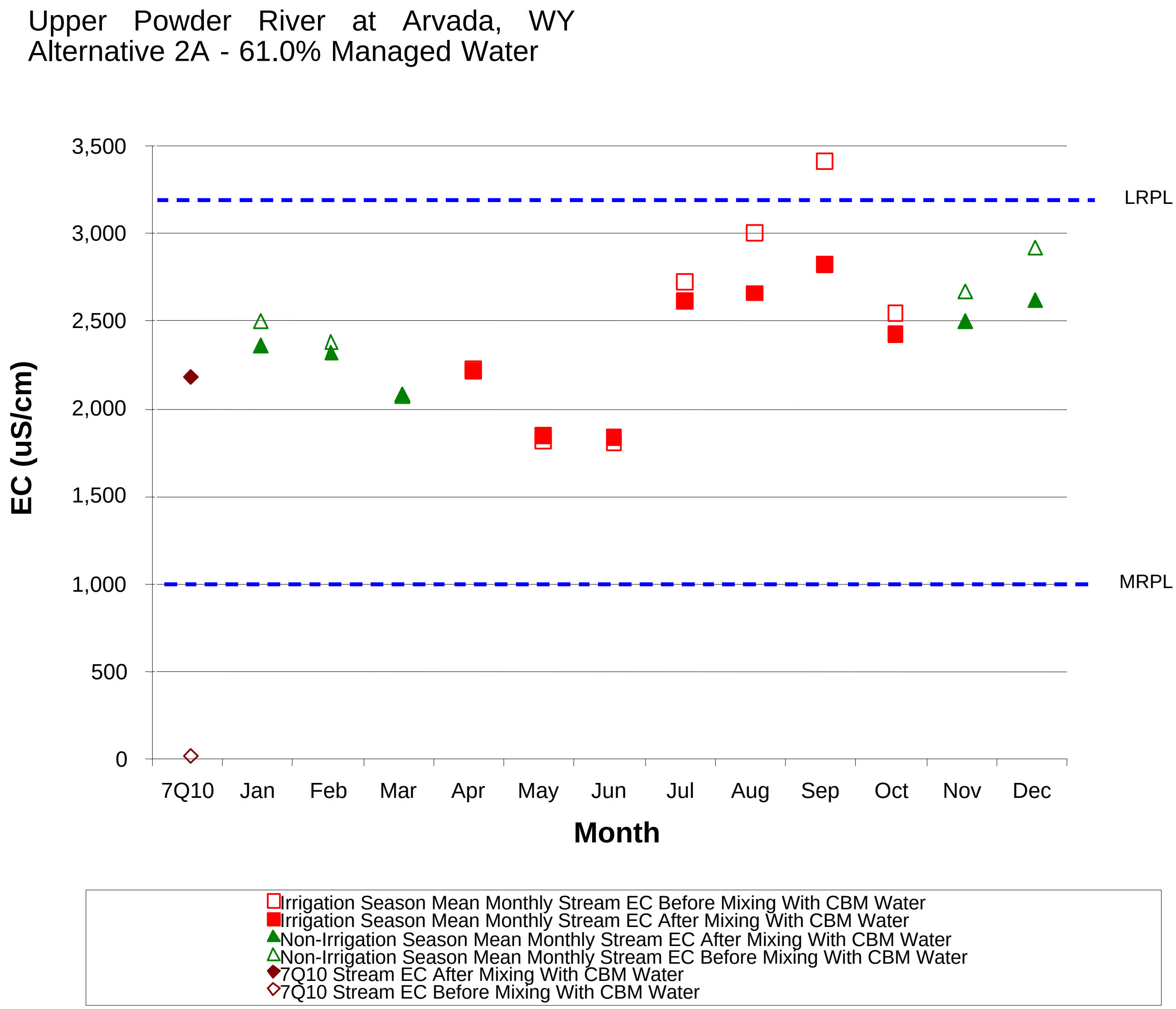


Figure 5-14 Stream SAR Before and After Mixing-Upper Powder River Sub-Watershed

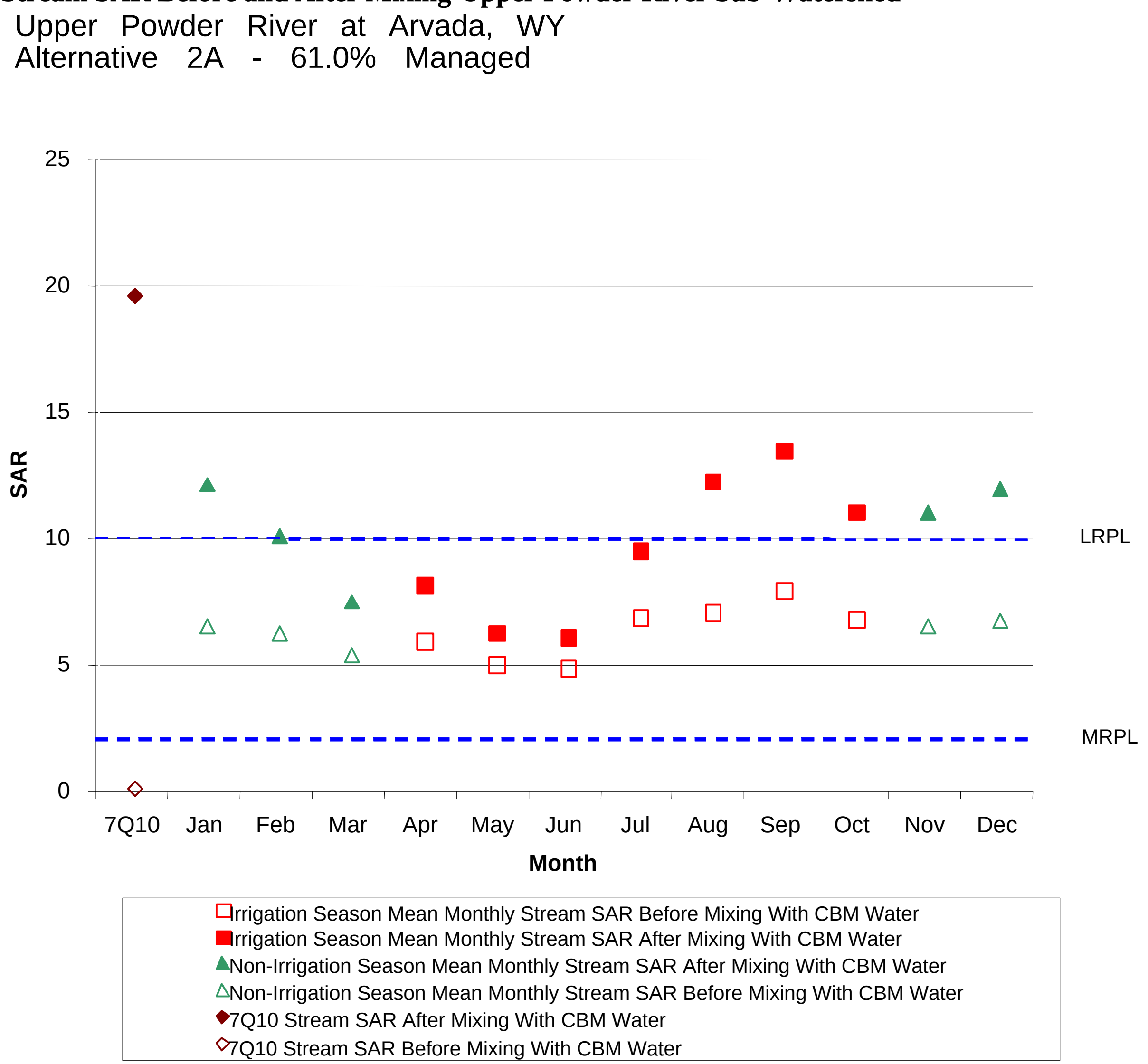


Figure 5-15 Irrigation Suitability Before and After Mixing – Upper Powder River Sub-Watershed

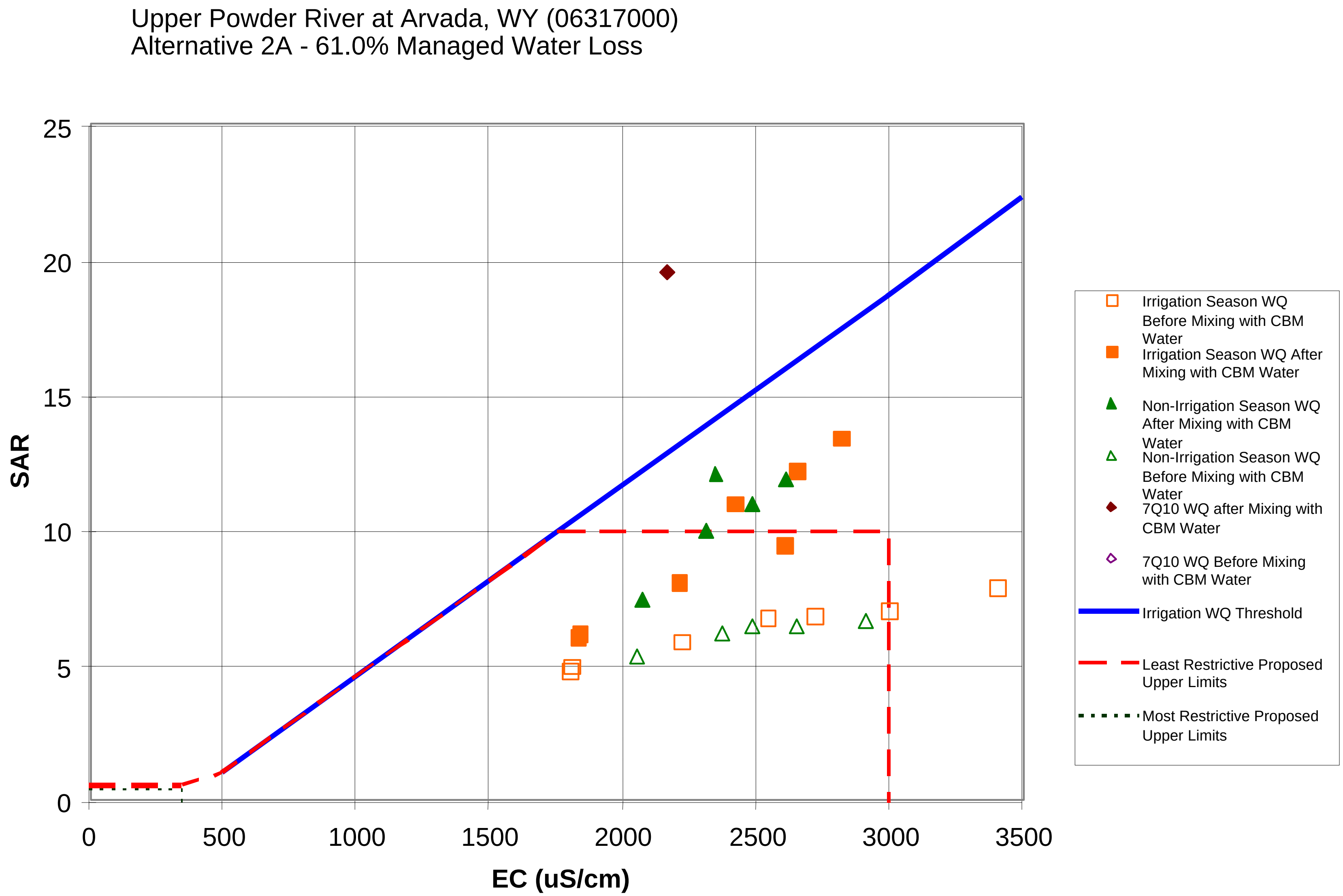
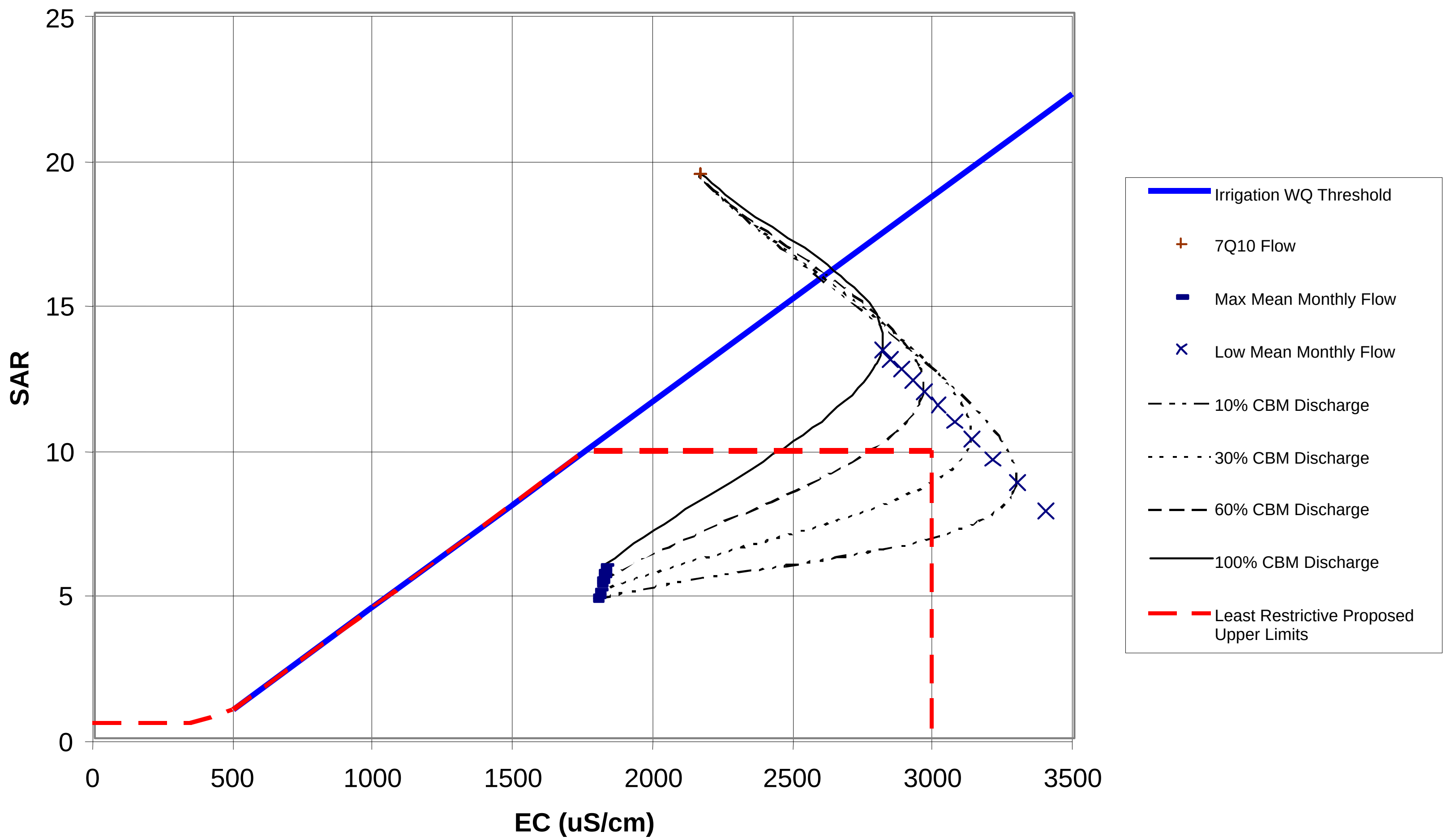


Figure 5-16 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Upper Powder River Sub-Watershed

Upper Powder River at Arvada, WY (06317000)
Alternative 2A - 61.0% Managed Water Loss



5.1.3.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1 primarily because of the increase in infiltration impoundments and implementation of active treatment. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Powder River sub-watershed during the peak year of CBM water production is about 63 cfs (45,616 acre-feet per year). The resultant flow and water quality would be similar to Alternative 1, but the magnitude of change from existing water quality would be less because of the reduced CBM discharges. Impacts to surface water quality would be similar to Alternative 1. Additional water would be available to support beneficial use as a result of the proportion of water that would undergo active treatment.

5.1.3.4 Alternative 3

Under Alternative 3, the peak of water production in the Upper Powder River sub-watershed would occur in year 2005, when 5,332 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Powder River sub-watershed during the peak year of CBM water production is about 45 cfs (32,583 acre-feet per year). Impacts to surface water quality would be similar to Alternative 1.

5.1.4 Clear Creek

Results of the impact analysis in the Clear Creek sub-watershed under each alternative are presented in Table 5-5. Potential impacts are discussed below.

Table 5-5
Surface Water Impact Analysis of the Clear Creek Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	2.0	1000	10	3200	62	1.5	1276	73	5.4	1522	0.1	3.96	3879	10	29.0	3030
2A	2.0	1000	10	3200				66	3.1	1378				4	28.6	3044
2B	2.0	1000	10	3200				65	2.8	1359				3	28.4	3049
3	2.0	1000	10	3200				70	4.5	1469				8	28.9	3033

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.1.4.1 Alternative 1

Under Alternative 1, the peak of water production in the Clear Creek sub-watershed would occur in year 2006, when 2,257 wells would be producing at an average rate of 6.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Clear Creek sub-watershed during the peak year of CBM water production is about 10 cfs (7,241 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC values in Clear Creek currently exceed the MRPL but are less than the LRPL during low-flow conditions. Mean monthly SAR values currently are less than the MRPL under similar flow conditions and are less than the LRPL during 7Q10 flow.
After the water mixes, the resultant stream flow under low-flow conditions would increase moderately from natural stream flow. The resulting EC and SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in Clear Creek near Arvada, Wyoming, would not be adequate to meet the MRPL for both EC and SAR, if it should be determined that the MRPL and LRPL criteria are protective of downstream irrigation uses. The only exception occurs during high flow in June,
- LRPL: The resultant water quality would be adequate to meet the LRPL for both constituents.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates no effects to infiltration except during 7Q10 flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

5.1.4.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1 primarily because of the increase in infiltration impoundments and lowered surface discharge. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Clear Creek sub-watershed during the peak year of CBM water production is about 4 cfs (2,896 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After the water mixes, the resultant stream flow under low-flow conditions would increase moderately from natural stream flow. The resulting EC and SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-17 and 5-18 illustrate the months during the year under Alternative 2A when the existing stream water quality and resultant mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL or LRPL adopted for water quality in the Clear Creek sub-watershed. Under modeled conditions, the resultant water quality in Clear Creek near Arvada, Wyoming, would not be adequate to meet the MRPL for both EC and SAR if it should be determined that the MRPL/LRPL criteria are protective of downstream irrigation uses. The only exception occurs during high flow in June.

- LRPL: The resultant water quality would be adequate to meet the LRPL for both constituents during all months, but not during 7Q10 flow conditions.
- Ayers and Westcot diagram: Figure 5-19 illustrates the relationship between EC and SAR in Clear Creek before and after the creek mixes with discharges of CBM produced water. Irrigation with the mixed water indicates no effects to infiltration except during 7Q10 flow conditions. Figure 5-20 illustrates the relationship between EC and SAR in Clear Creek after the creek mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Based on the higher water quality of the stream and its value as a source of irrigation water in the Clear Creek sub-watershed, WDEQ would not allow any new discharge permits under Alternatives 1 or 2A that would result in any decrease in baseline water quality. Because of WDEQ's policy, it is expected that water quality in Clear Creek would be preserved at near current levels.

Figure 5-17 Stream EC Before and After Mixing-Clear Creek Sub-Watershed

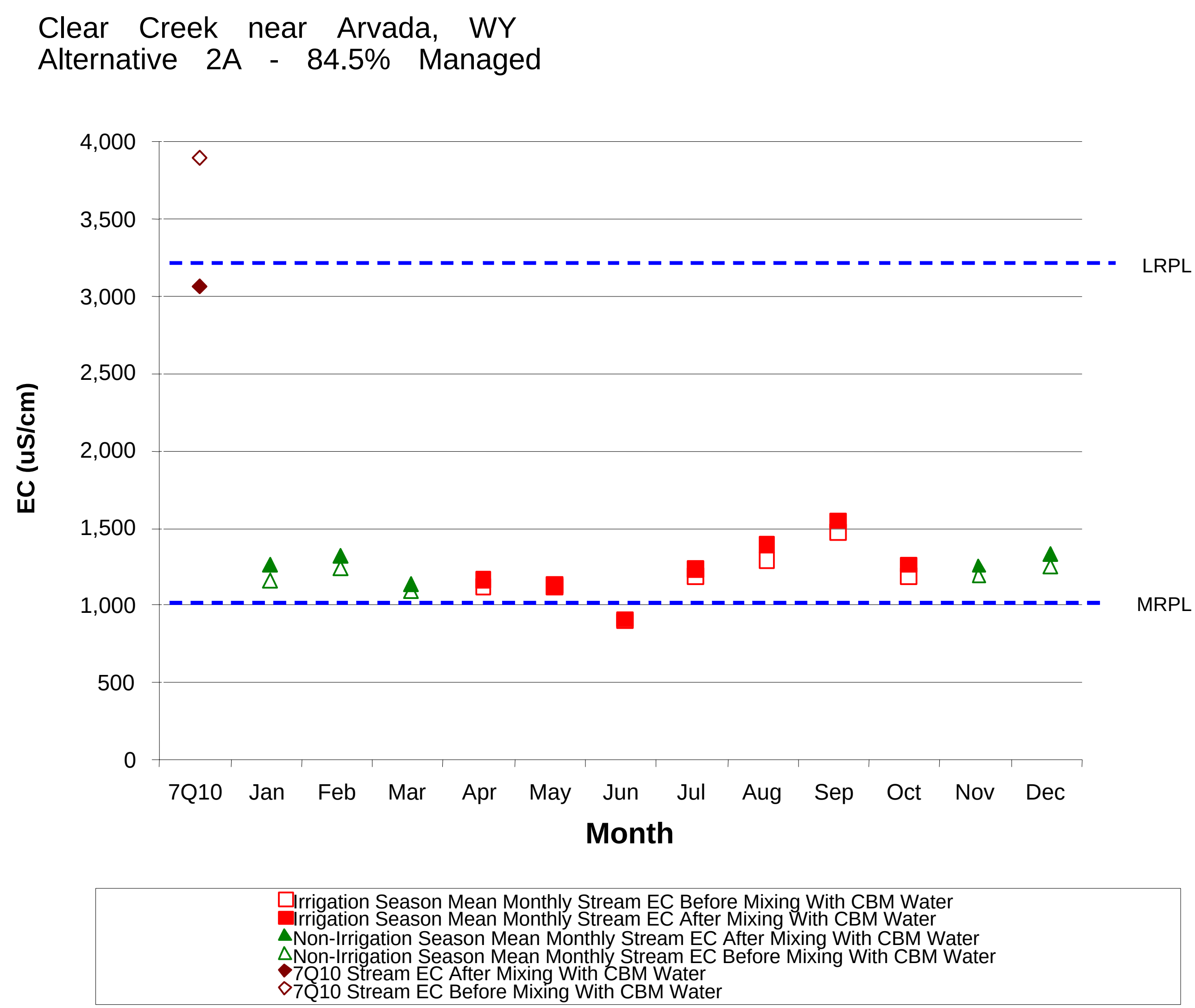


Figure 5-18 Stream SAR Before and After Mixing- Clear Creek Sub-Watershed

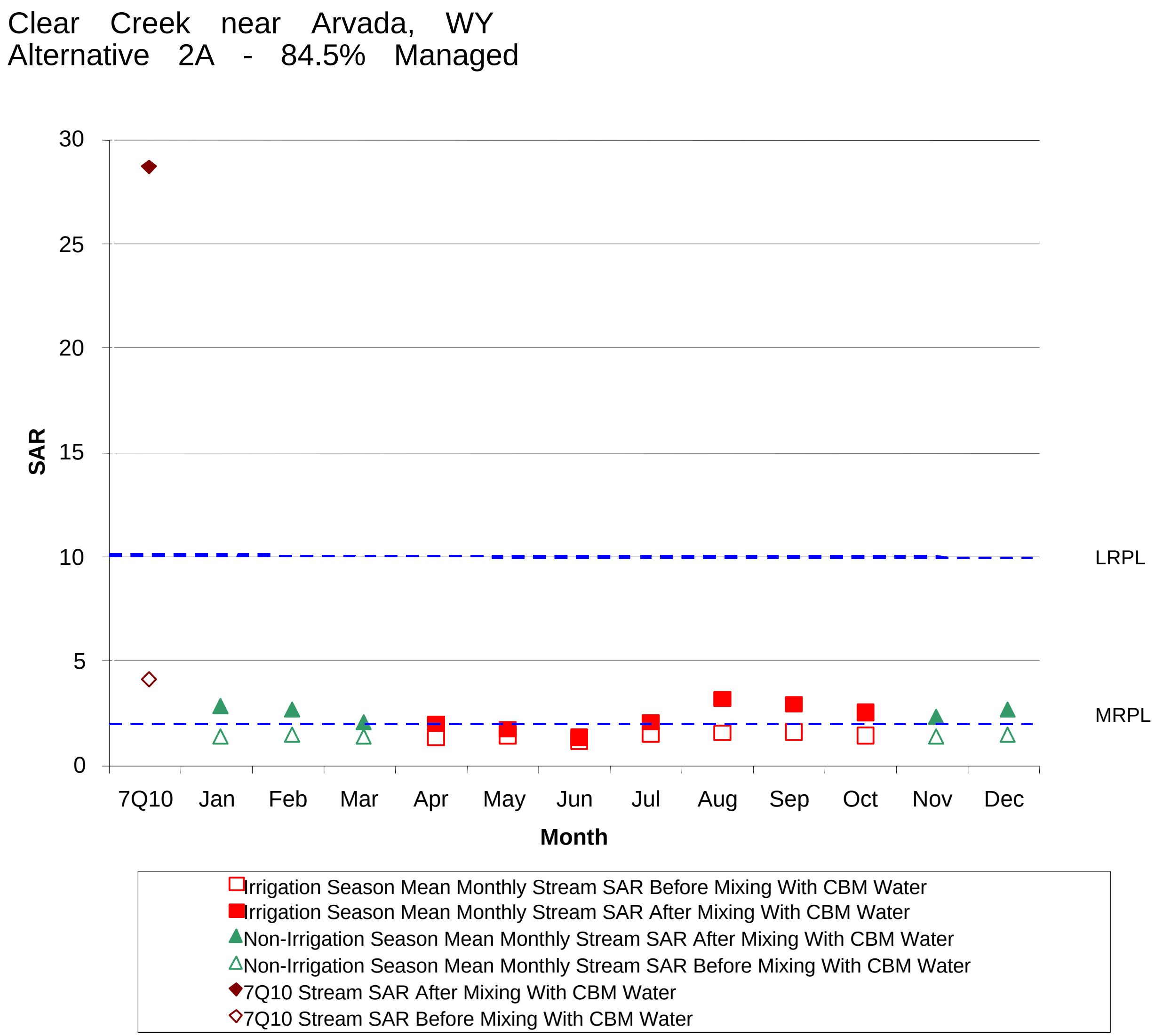


Figure 5-19 Irrigation Suitability Before and After Mixing – Clear Creek Sub-Watershed

Clear Creek near Arvada, WY (06324000)
Alternative 2A - 84.5% Managed Water Loss

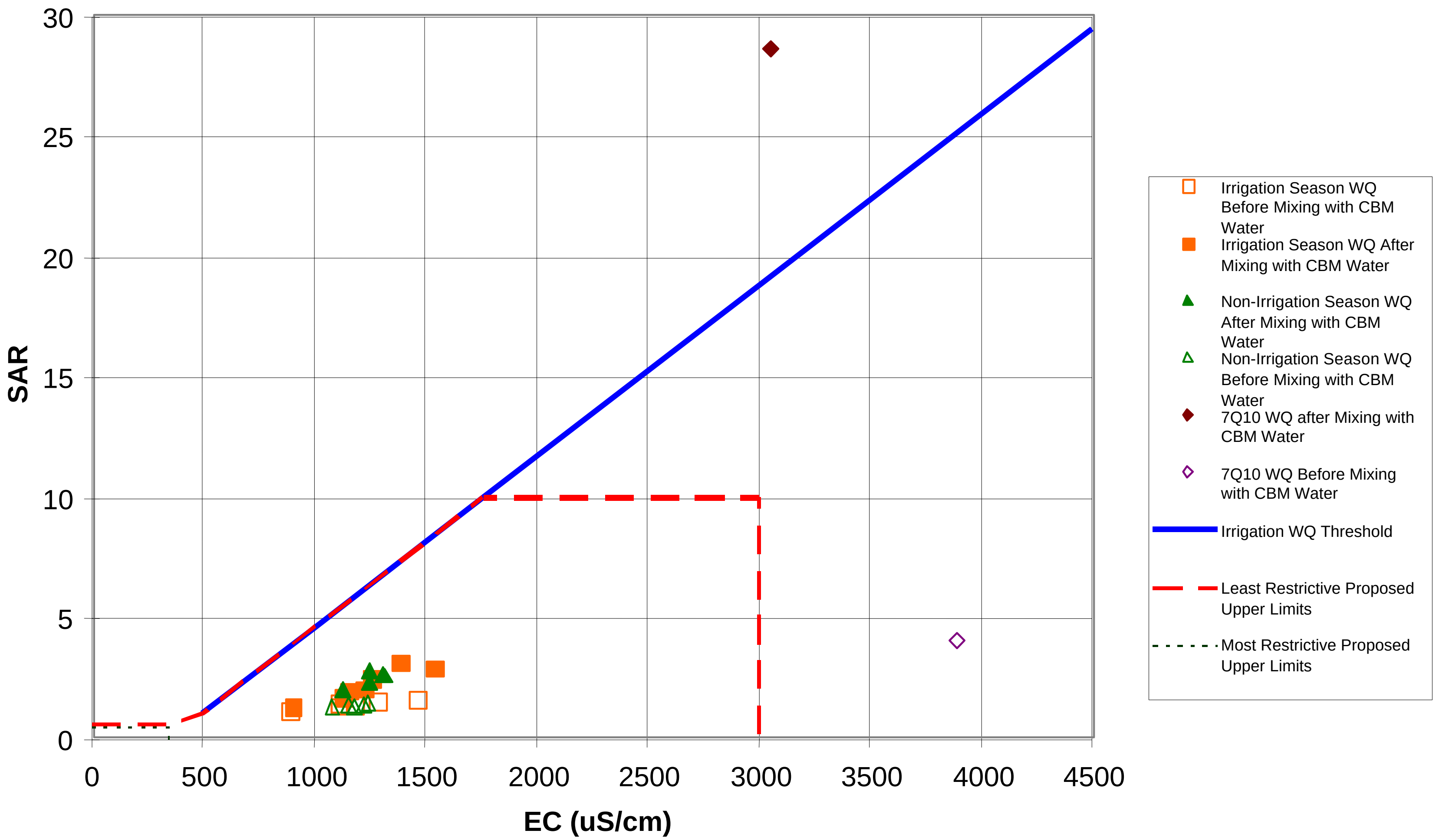
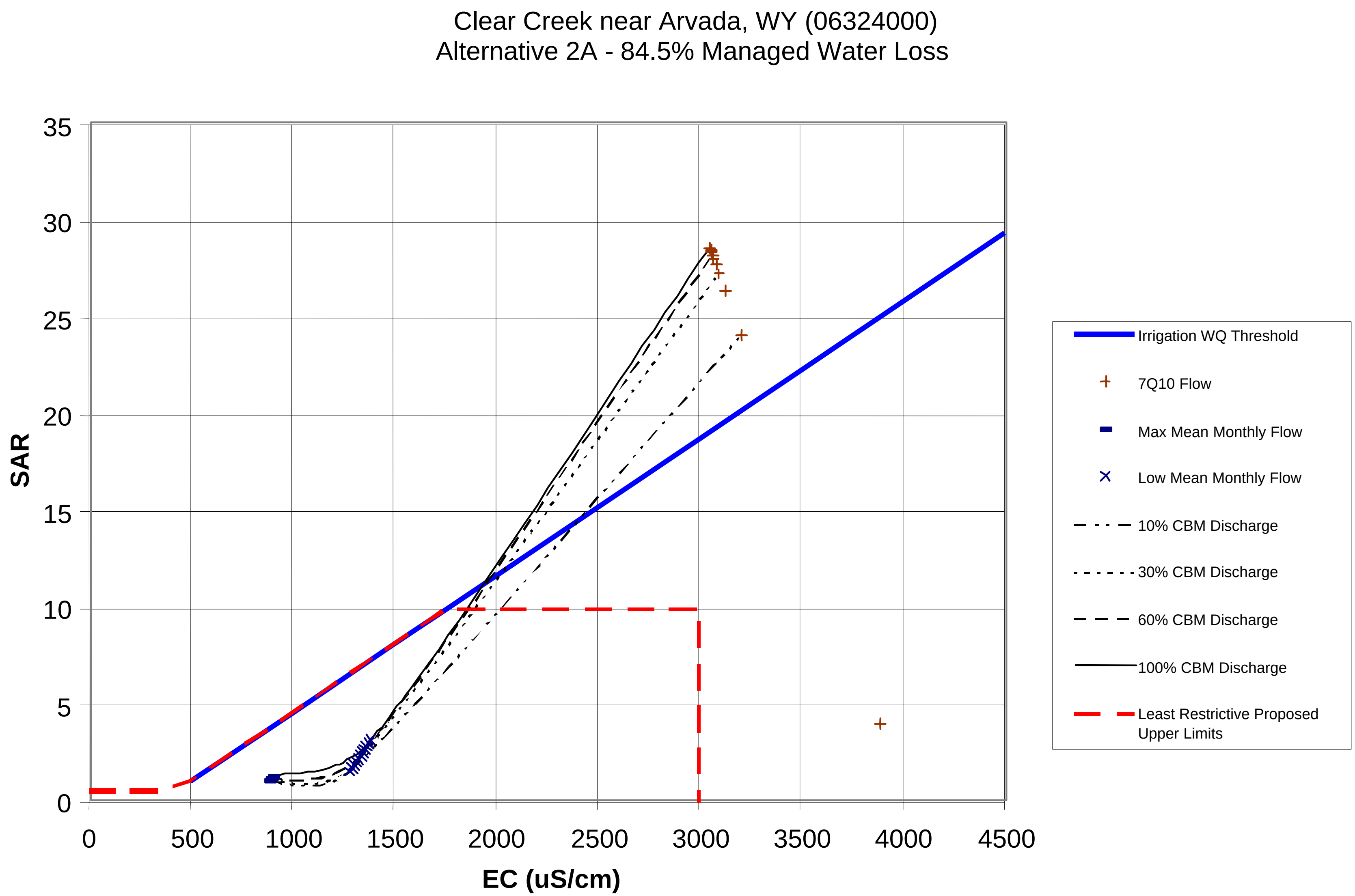


Figure 5-20 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Clear Creek Sub-Watershed



5.1.4.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1 primarily because of the increase in infiltration impoundments and implementation of active treatment, along with lowered surface discharge. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Clear Creek sub-watershed during the peak year of CBM water production is about 3 cfs (2,172 acre-feet per year). Under Alternative 2B, the resultant SAR would be adequate to meet the MRPL during high flows in April through June but not during the remainder of the irrigation season, when natural stream flow decreases. Remaining impacts to surface water quality would be similar to the results obtained under Alternative 1. Additional water would be available to support beneficial use because of the proportion of water that would undergo active treatment.

5.1.4.4 Alternative 3

Under Alternative 3, the peak of water production in the Clear Creek sub-watershed would occur in year 2006, when 1,705 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Clear Creek sub-watershed during the peak year of CBM water production is about 8 cfs (5,793 acre-feet per year). Impacts to surface water quality would be similar to Alternative 1.

5.1.5 Crazy Woman Creek

Results of the impact analysis in the Crazy Woman Creek sub-watershed under each alternative are presented in Table 5-6. Potential impacts are discussed below.

Table 5-6
Surface Water Impact Analysis of the Crazy Woman Creek Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	2.0	1000	10	3200	14	2.3	1937	28	13.8	2545	0.0	--	--	14	24.8	3129
2A	2.0	1000	10	3200				17	6.5	2159				3	24.8	3129
2B	2.0	1000	10	3200				16	5.6	2112				2	24.8	3129
3	2.0	1000	10	3200				19	8.0	2240				5	24.8	3129

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.1.5.1 Alternative 1

Under Alternative 1, the peak of water production in the Crazy Woman Creek sub-watershed would occur in year 2006, when 1,853 wells would be producing at an average rate of 6.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Crazy Woman Creek sub-watershed during the peak year of CBM water production is about 14 cfs (10,137 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC values in Crazy Woman Creek currently exceed the MRPL but are less than the LRPL under low-flow conditions. Mean monthly SAR values currently are about equal to the MRPL under similar flow conditions. After the water mixes, the resultant stream flow under low-flow conditions would nearly double from natural stream flow. The resultant EC would decrease, whereas the SAR would increase from existing conditions. The existing 7Q10 flow is calculated as zero; therefore, it is assumed that the resultant water quality under this flow would be represented by the quality of the CBM produced water if discharges were to occur during critical low-flow periods. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in Crazy Woman Creek near Arvada, Wyoming, during all months and during 7Q10 flow conditions would not be adequate to meet the MRPL for EC and SAR if it should be determined that the MRPL and LRPL criteria are protective of downstream irrigation uses.
- LRPL: Under modeled conditions, the resultant water quality would be adequate to meet the LRPL for EC during all months, but not during 7Q10 flow conditions. With the exception of during low flows from August through February and during 7Q10 flow conditions, the resultant water quality would be adequate to meet the LRPL for SAR.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates no effects to infiltration, except during 7Q10 flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

5.1.5.1 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and lowered surface discharge. Under modeled conditions, the amount of produced water that is assumed to reach the main stem of the Crazy Woman Creek sub-watershed during the peak year of CBM water production is about 3 cfs (2,172 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After the water mixes, the resultant stream flow under low-flow conditions would nearly double from natural stream flow. The resultant EC would decrease, whereas the SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-21 and 5-22 illustrate the months during the year under Alternative 2A when the existing stream water quality and resultant mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL or LRPL adopted for water quality in the Crazy Woman Creek sub-watershed. Under modeled conditions, the resultant water quality in Crazy Woman Creek near Arvada, Wyoming, during all months and during 7Q10 flow conditions would not be adequate to meet the MRPL for EC and SAR if it should be determined that the MRPL and LRPL criteria are protective of downstream irrigation uses.
- LRPL: Under modeled conditions, the resultant water quality would be adequate to meet the LRPL for EC during all months, but not during 7Q10 flow conditions. With the exception of low flows during August through February and during 7Q10 flow conditions, the resultant water quality in Crazy Woman Creek near Arvada, Wyoming, would be adequate to meet the LRPL for SAR.
- Ayers and Westcot diagram: Figure 5-23 illustrates the relationship between EC and SAR in Crazy Woman Creek before and after the creek mixes with discharges of CBM produced water. Irrigation with the mixed water indicates no effects to infiltration except during 7Q10 flow conditions. Figure 5-24 illustrates the relationship between EC and SAR in Crazy Woman Creek after the creek mixes with varying proportions of CBM produced water discharges under various stream flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Based on the higher water quality and its value as a source of irrigation water in the sub-watershed, WDEQ would not allow any new discharge permits in this sub-watershed under Alternatives 1 or 2A that would result in any decrease in baseline water quality. Because of WDEQ's policy, it is expected that water quality in Crazy Woman Creek would be preserved at near current levels.

Figure 5-21 Stream EC Before and After Mixing-Crazy Woman Creek Sub-Watershed

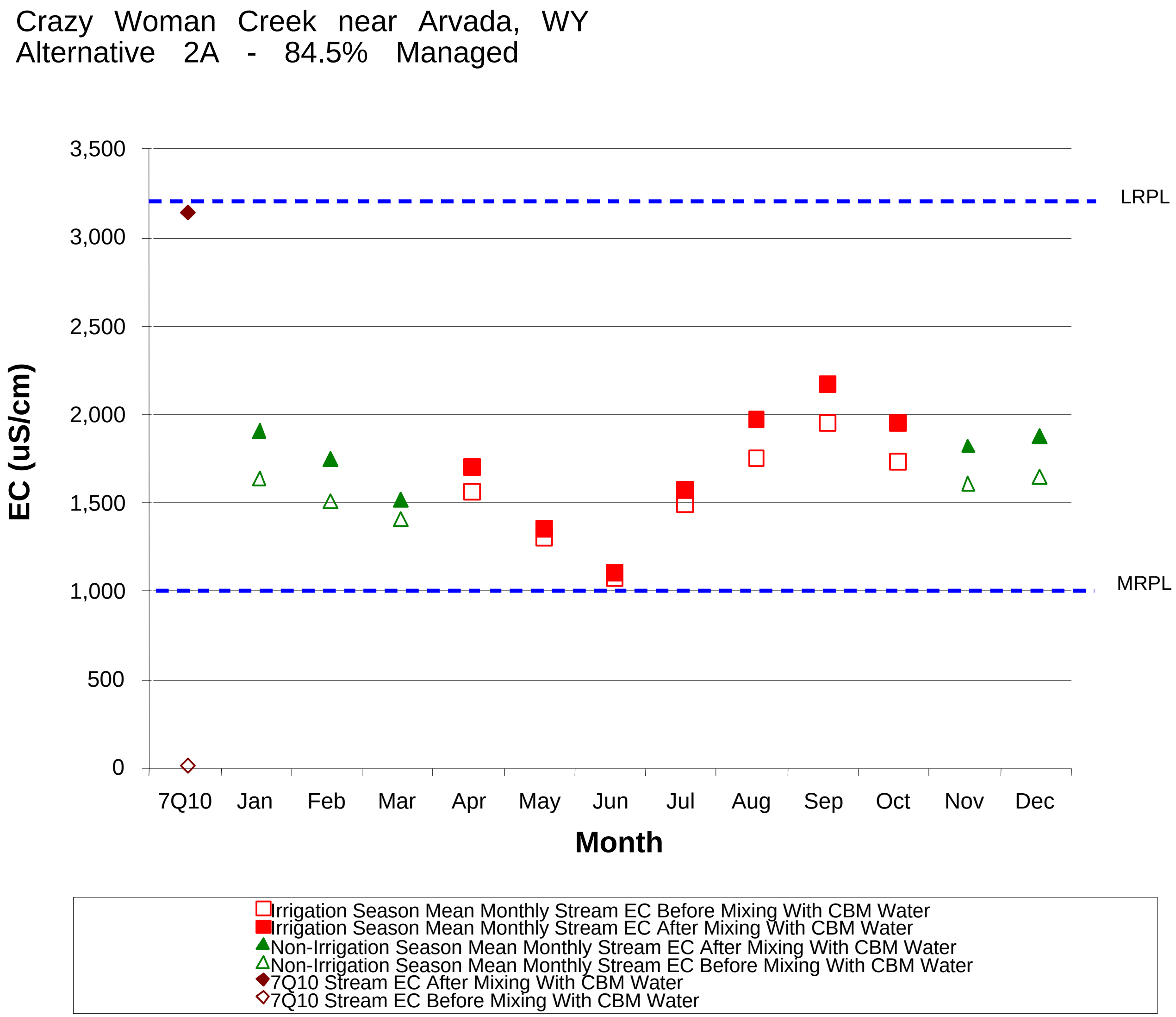


Figure 5-22 Stream SAR Before and After Mixing- Crazy Woman Creek Sub-Watershed

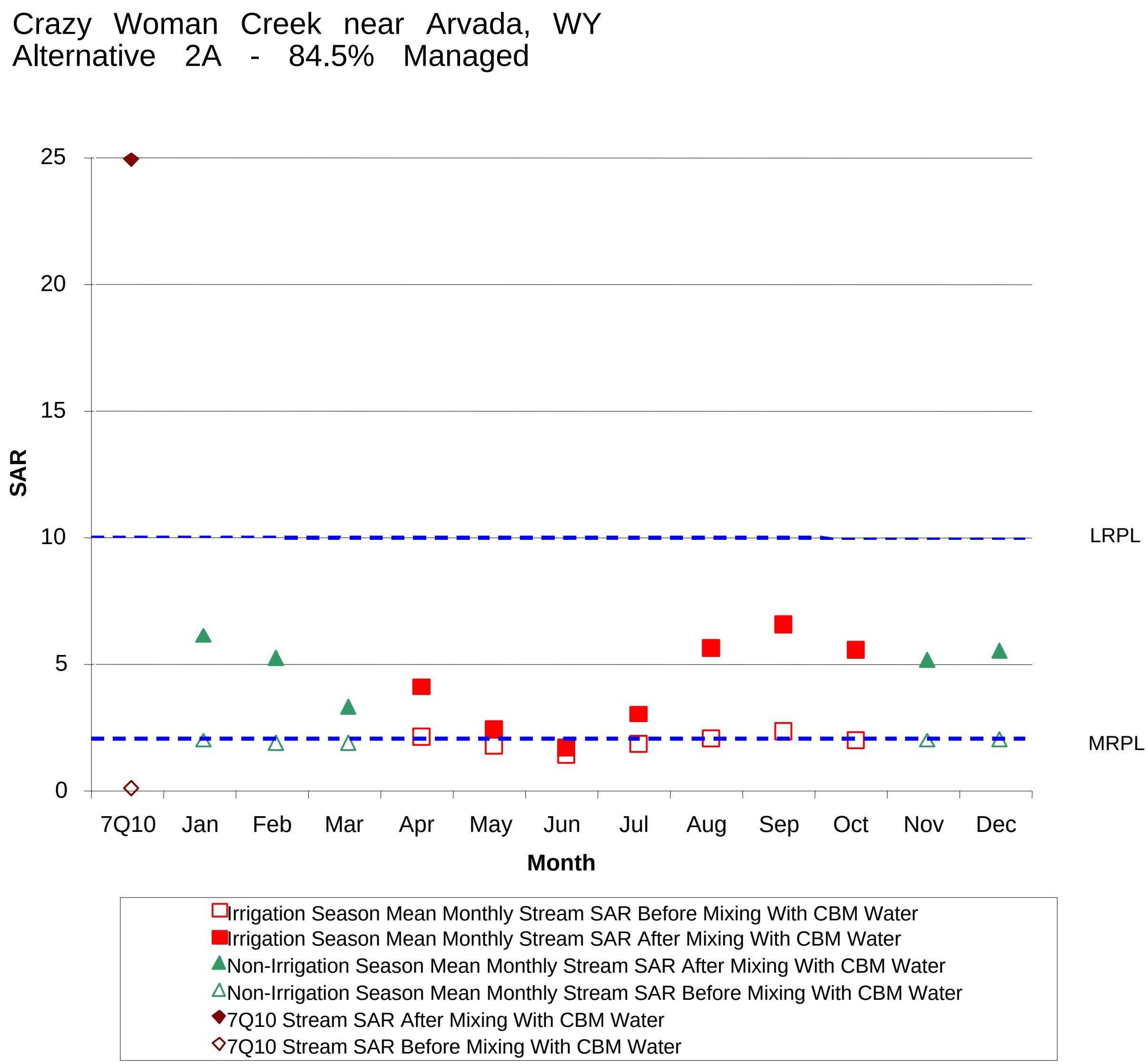


Figure 5-23 Irrigation Suitability Before and After Mixing – Crazy Woman Creek Sub-Watershed

Crazy Woman Creek near Arvada, WY (06316400)
Alternative 2A - 84.5% Managed Water Loss

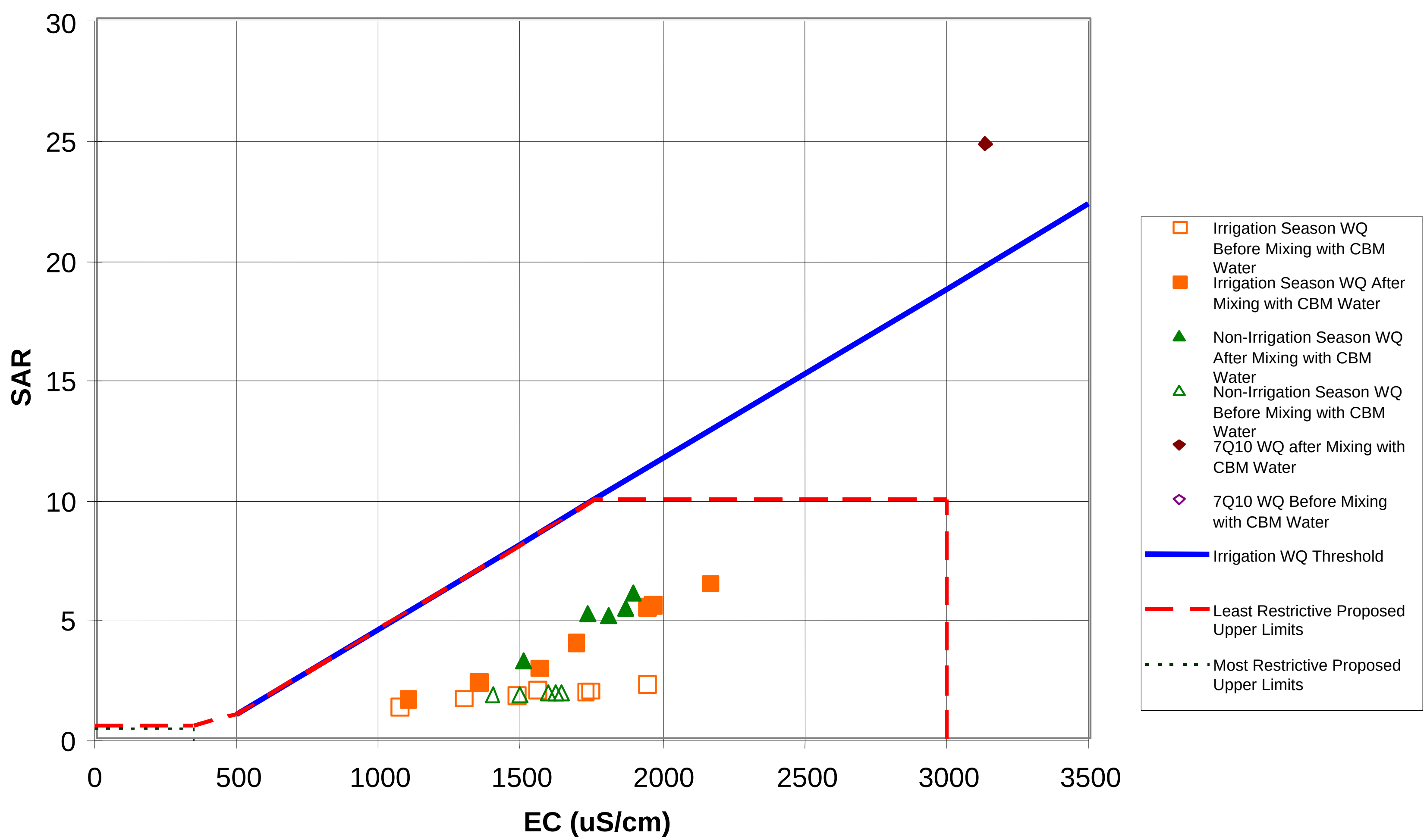
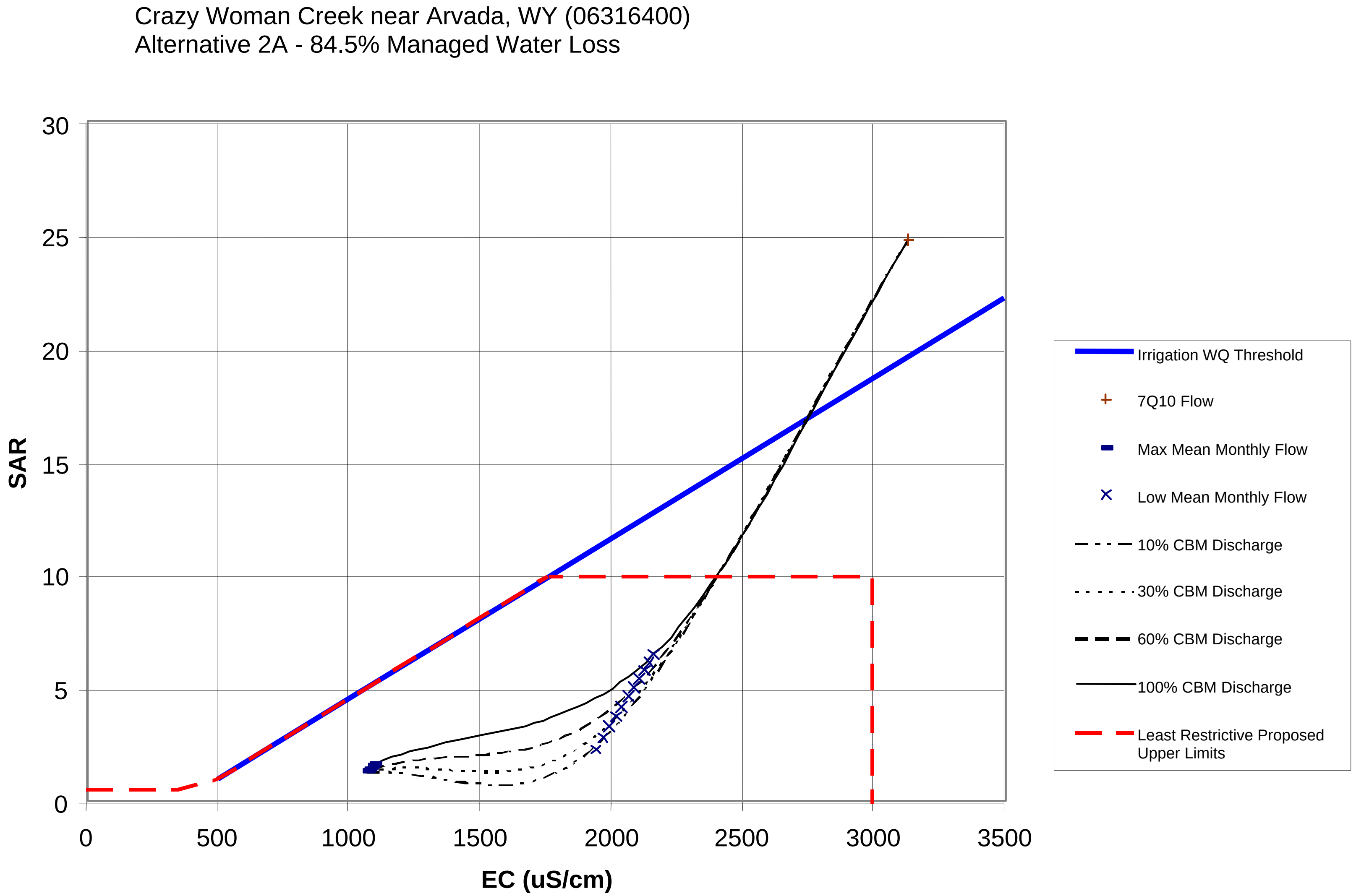


Figure 5-24 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Crazy Woman Creek Sub-Watershed



5.1.5.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and implementation of active treat4949ment, along with lowered surface discharge. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Crazy Woman Creek sub-watershed during the peak year of CBM water production is about 2 cfs (1,448 acre-feet per year). Impacts to surface water quality would be similar to Alternative 2A. Additional water would be available to support beneficial use because of the proportion of water that would undergo active treatment.

5.1.5.4 Alternative 3

Under Alternative 3, the peak of water production in the Crazy Woman Creek sub-watershed would occur in year 2005, when 606 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Crazy Woman Creek sub-watershed during the peak year of CBM water production is about 5 cfs (3,620 acre-feet per year). Impacts to surface water quality would be similar to Alternative 2A.

5.1.6 Salt Creek

Results of the impact analysis for the Salt Creek sub-watershed under each alternative are presented in Table 5-7. Potential impacts are discussed below.

Table 5-7
Surface Water Impact Analysis of the Salt Creek Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	2.0	1000	10	3200	27	26.1	5750	27	25.9	5711	8.4	25.1	6741	8.6	24.7	6588
2A	2.0	1000	10	3200				27	26.0	5743				8.4	25.0	6714
2B	2.0	1000	10	3200				27	26.1	5750				8.4	25.0	6721
3	2.0	1000	10	3200				27	26.0	5730				8.5	24.9	6662

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.1.6.1 Alternative 1

Under Alternative 1, the peak of water production in the Salt Creek sub-watershed would occur in year 2006, when 37 wells would be producing at an average rate of 6.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Salt Creek sub-watershed during the peak year of CBM water production is about 0.2 cfs (145 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

The water quality in Salt Creek currently exceeds the MRPL or LRPL for both EC and SAR under low-flow conditions. After the water mixes, the resultant stream flow under low monthly flow conditions would be similar to the natural stream flow. The resultant EC and SAR would decrease slightly from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in Salt Creek near Sussex, Wyoming, during all months and during 7Q10 flow conditions would not be adequate to meet the MRPL for both EC and SAR if it should be determined that the MRPL and LRPL criteria are protective of downstream irrigation uses.
- LRPL: The resultant water quality would not be adequate to meet the LRPL for both EC and SAR under similar flow conditions.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates no effects to infiltration under similar flow conditions. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

5.1.6.2 Alternative 2A

Under Alternative 2A, there would be no surface discharge to the Salt Creek sub-watershed. Minimal amounts of subsurface flow from infiltration impoundments would resurface in stream channels but are not likely to reach the main stem of the Salt Creek sub-watershed. Under Alternative 2A, impacts to surface water quality would be similar to the results obtained under Alternative 1.

5.1.6.3 Alternative 2B

Under Alternative 2B, there would be no untreated surface discharge to the Salt Creek sub-watershed. Minimal amounts of subsurface flow from infiltration impoundments would resurface in stream channels but are not likely to reach the main stem of the Salt Creek sub-watershed. Under Alternative 2B, impacts to surface water quality would be similar to the results obtained under Alternative 1. Additional water would be available to support beneficial use because of the proportion of water that would undergo active treatment.

5.1.6.4 Alternative 3

Under Alternative 3, the peak of water production in the Salt Creek sub-watershed would occur in year 2006, when 19 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Salt Creek sub-watershed during the peak year of CBM water production is about 0.1 cfs (72 acre-feet per year). Impacts to surface water quality would be similar to Alternative 1.

5.2 Wyoming/Montana Streams

5.2.1 Upper Tongue River

The impact analysis of surface water in the Upper Tongue River sub-watershed incorporates current and forecast future development of CBM resources in the Montana portion of the Upper Tongue River sub-watershed. These flows are likely to contribute to flows of CBM produced water upstream of the USGS gauging station on the Tongue River at the state line near Decker, Wyoming.

This analysis assumed that the Montana Preferred Alternative E would be adopted. Montana's Alternative E emphasizes beneficial uses of produced water from CBM wells. Alternative E could include discharges of produced water that involve both treated and untreated water, so long as MPDES permit requirements are met. This impact analysis includes existing discharges of CBM produced water in the Upper Tongue River sub-watershed from Montana's CX Ranch field. Montana's existing permitted discharge incorporated in this modeling effort includes produced water from 120 wells at a discharge rate of 50 percent of the permitted maximum discharge (Langhus 2002).

Results of the impact analysis in the Upper Tongue River sub-watershed under each alternative are presented in Table 5-8. Potential impacts are discussed below.

Table 5-8
Surface Water Impact Analysis of the Upper Tongue River Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	0.5	500	10	2500	178	0.9	731	189	3.1	826	43	1.29	1179	54	8.98	1423
2A	0.5	500	10	2500				183	1.9	776				48	5.38	1304
2B	0.5	500	10	2500				183	1.8	770				48	4.92	1288
3	0.5	500	10	2500				188	2.9	820				53	8.56	1409

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.2.1.1 Alternative 1

Under Alternative 1, the peak of water production in the Upper Tongue River sub-watershed would occur in year 2006, when 1,948 wells would be producing at an average rate of 6.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Tongue River sub-watershed during the peak year of CBM water production is about 11 cfs (7,965 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

The Tongue River is an important source of irrigation water in and downstream of the Project Area. With the exception of the highest flow months of May and June, the water quality in the Tongue River currently exceeds the MRPL for EC and SAR; thus, any additional discharge that would reach the main stem would likely cause further degradation in terms of suitability irrigation if the states and EPA conclude that the MRPL is protective of irrigation uses. The water quality in the Tongue River currently is below the LRPL for both EC and SAR during all months and during 7Q10 flow conditions.

After the water mixes, the resultant flow under low monthly flow conditions would increase slightly. The resultant EC and SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Upper Tongue River would not meet the MRPL for EC, with the exception during high flows in May and June. The resultant water quality would not be adequate to meet the MRPL for SAR during all months and during 7Q10 flow conditions.
- LRPL: Under modeled conditions, the resultant water quality would be adequate to meet the LRPL for both EC and SAR during all months of the year and during 7Q10 flow conditions.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates that some reduction in infiltration would be likely during some months of the irrigation season. During the low monthly flow, about 70 percent of the CBM discharge could occur without causing potential effects to infiltration.

Based on modeled results, impacts to the suitability for irrigation of the Upper Tongue River sub-watershed from CBM development in Wyoming and Montana under Alternative 1 would be expected to occur at the state line station near Decker, Wyoming, using the MRPL and LRPL criteria if the states and EPA conclude that the proposed limits would be protective of irrigation uses. However, surface discharge to the Upper Tongue River sub-watershed from CBM development in Wyoming would be controlled by WDEQ’s interim “no new discharge” policy. Thus, the percentage of untreated surface discharge to the Upper Tongue River sub-watershed under Alternative 1 would not be authorized by WDEQ unless the quality of the discharged water was at or near the existing quality in the Tongue River. Potential impacts from Montana’s existing CBM discharges from the CX Ranch field to the Upper Tongue River sub-watershed would be controlled by the current MPDES permit. Therefore, impacts to water quality would be more likely to result from CBM produced waters that resurface from infiltration impoundments or from migration of salts beneath LAD systems than from surface discharge. Impacts to water quality from CBM development in Wyoming to downstream uses on the Northern Cheyenne Reservation would be limited by the state’s discharge policy.

5.2.1.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and lowered surface discharge. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Tongue River sub-watershed during the peak year of CBM water production is about 5 cfs (3,620 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After the water mixes, the resultant flow under low monthly flow conditions would increase slightly. The resultant EC and SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-25 and 5-26 are used to illustrate the months during the year when the existing water quality and resultant mixed water quality under mean monthly flow and 7Q10 flow conditions would exceed the MRPL and LRPL being considered for water quality in the Upper Tongue River sub-watershed. Under modeled conditions, the resultant water quality under mean monthly and 7Q10 flow conditions exceeds the MRPL for EC and SAR when CBM produced water discharges from both states are mixed, except during the highest flow months of May and June.
- LRPL: Under modeled conditions, the resultant water quality under mean monthly and 7Q10 flow conditions is less than the LRPL for both constituents when CBM produced water discharges from both states are mixed.
- Ayers and Westcot diagram: Figure 5-27 illustrates the relationship between EC and SAR in the Upper Tongue River before and after the river mixes with discharges of CBM produced water under Wyoming's Alternative 2A and Montana's Alternative E. Under modeled conditions, a comparison of the resultant quality of the mixed water with the Ayers-Westcot diagram in Figure 5-27 indicates that a reduction in infiltration is not likely under mean monthly or 7Q10 flow conditions. Figure 5-28 illustrates the relationship between EC and SAR in the Upper Tongue River after the river mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially all of the CBM discharge to the Upper Tongue River sub-watershed from both states could occur during the low monthly flow and during 7Q10 flow without causing effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Figure 5-25 Stream EC Before and After Mixing-Upper Tongue River Sub-Watershed

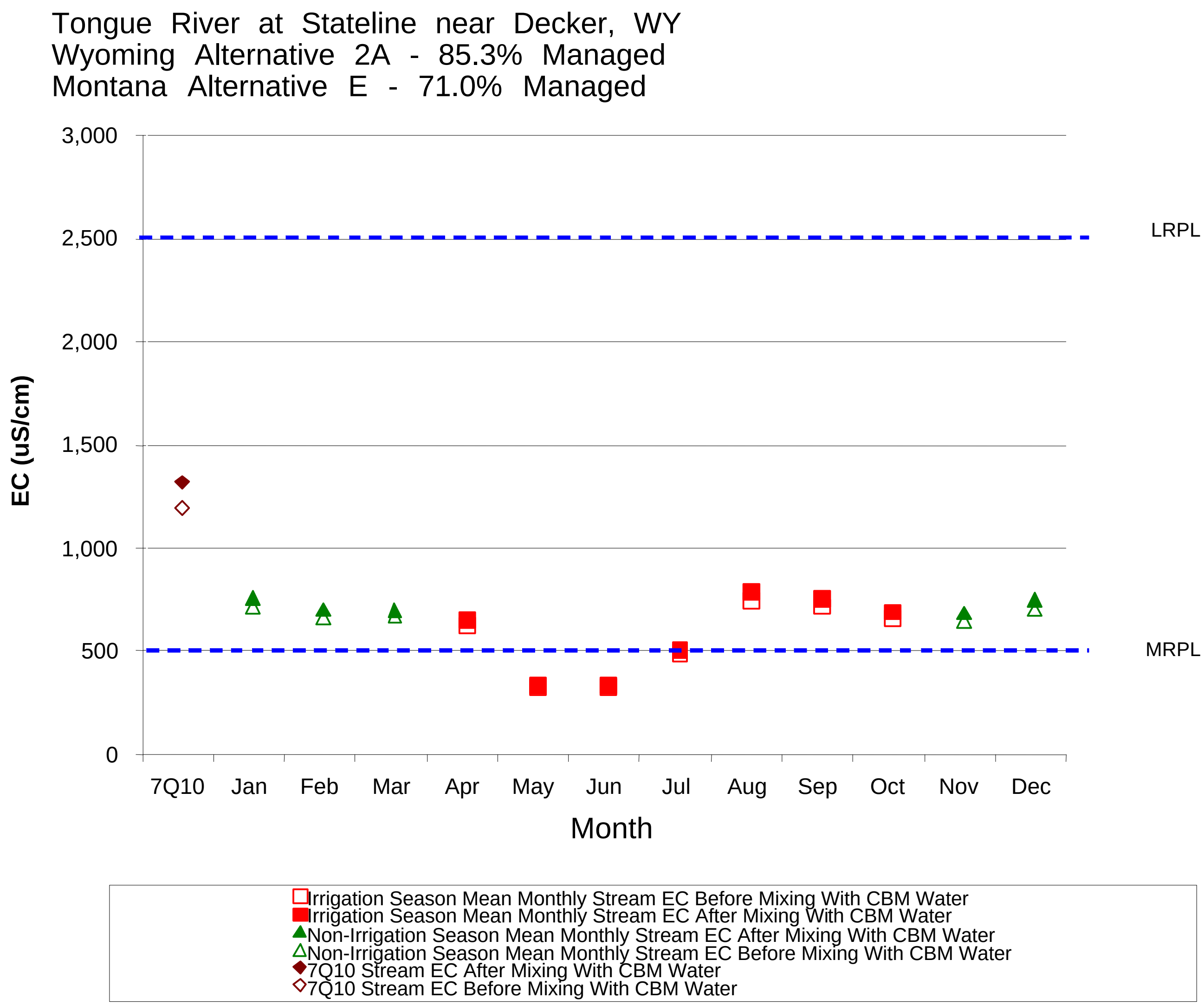


Figure 5-26 Stream SAR Before and After Mixing-Upper Tongue River Sub-Watershed

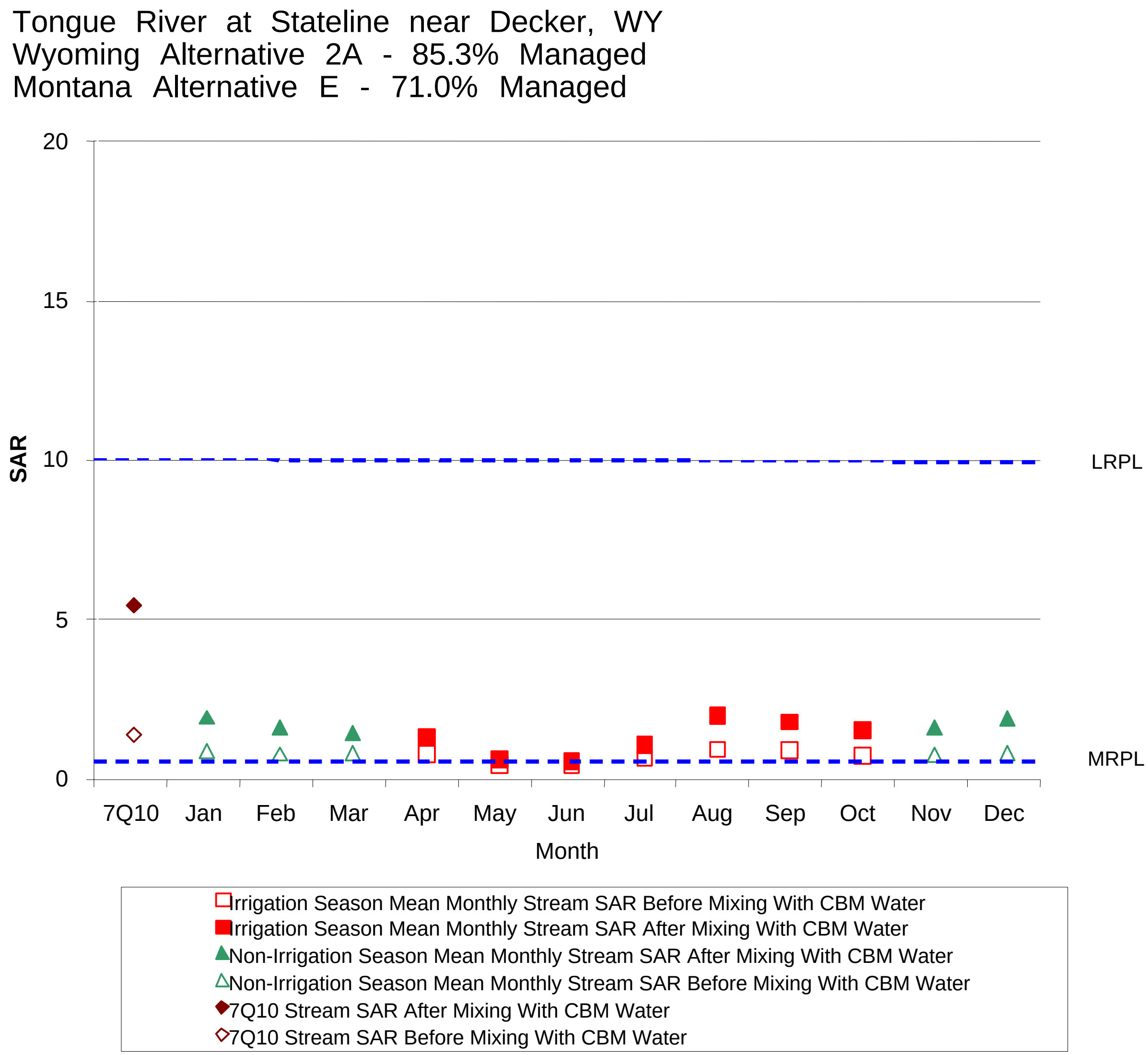


Figure 5-27 Irrigation Suitability Before and After Mixing – Upper Tongue River Sub-Watershed

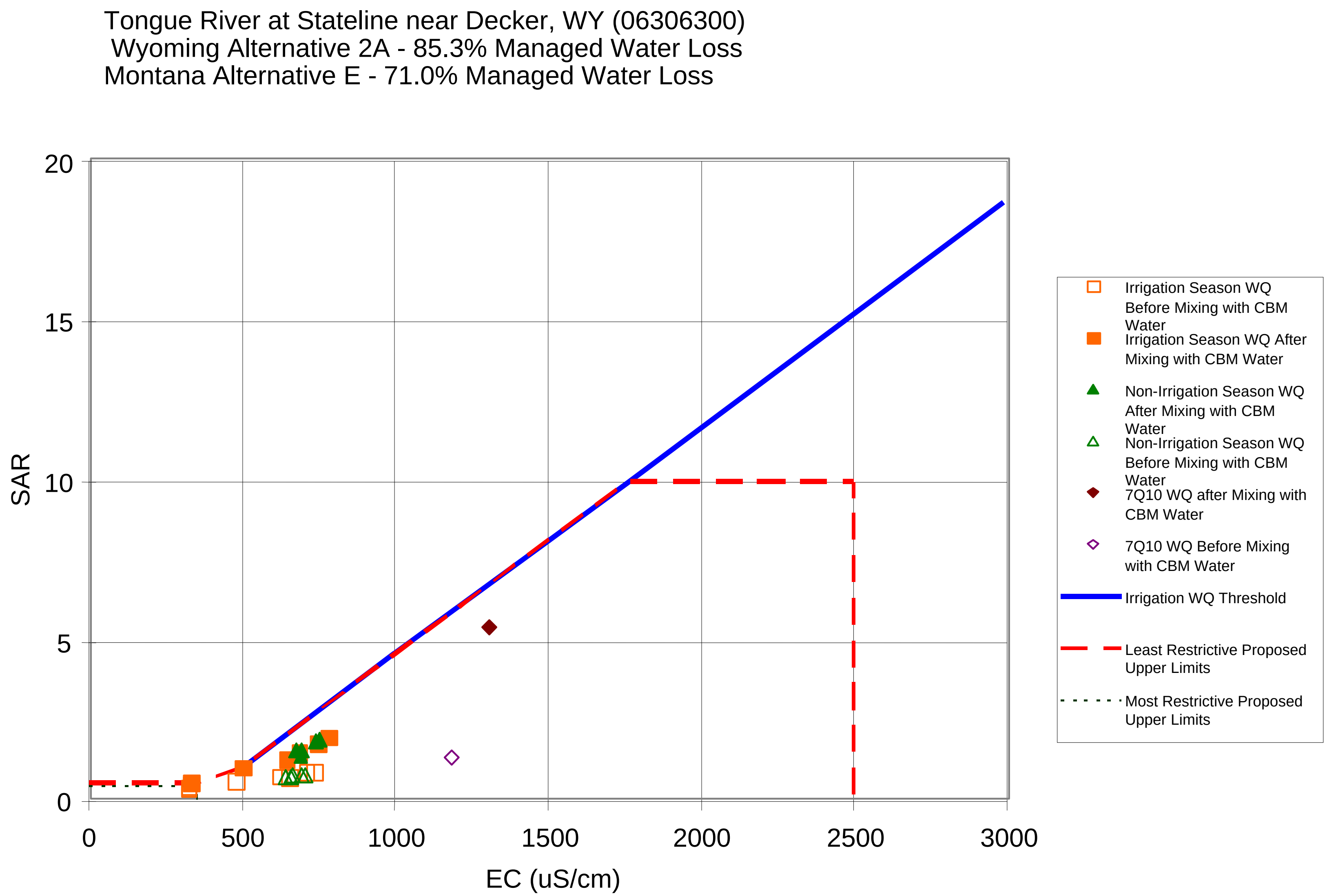
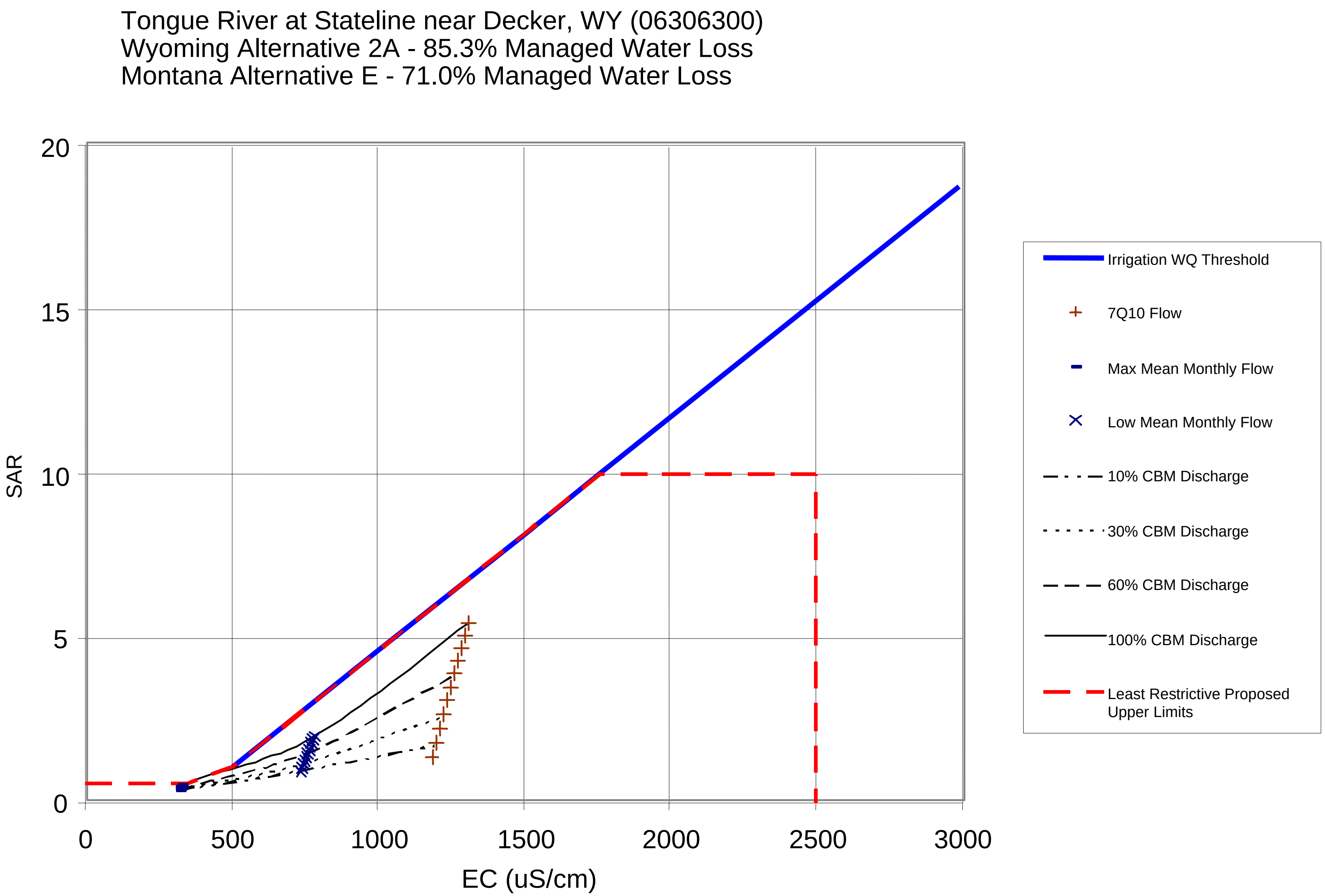


Figure 5-28 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Upper Tongue River Sub-Watershed



Based on modeled results, impacts to the suitability for irrigation of the Tongue River from CBM development in Wyoming and Montana under Alternative 2A would not be expected to occur.

5.2.1.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in LAD for water handling and implementation of active treatment. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Tongue River sub-watershed during the peak year of CBM water production is about 4 cfs (2,896 acre-feet per year). Impacts to surface water quality in the Upper Tongue River sub-watershed would be less than were described under Alternative 1 and similar to those described for Alternative 2A. Additional water would be available to support beneficial use because of the proportion of water that would undergo active treatment.

5.2.1.4 Alternative 3

Under Alternative 3, the peak of water production in the Upper Tongue River sub-watershed would occur in year 2006, when 1,786 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Upper Tongue River sub-watershed during the peak year of CBM water production is about 10 cfs (7,241 acre-feet per year). Impacts to surface water quality in the Upper Tongue River sub-watershed would be similar to Alternative 1.

5.2.2 Powder River

The impact analysis of surface water in the Middle Powder River sub-watershed incorporates the cumulative discharges of CBM produced water from the Clear Creek, Crazy Woman Creek, Salt Creek, and Upper Powder River sub-watersheds. The analysis also includes current and future forecast development of CBM resources in the Montana portion of the Middle Powder River sub-watershed that would be likely to contribute flows of CBM produced water upstream of the USGS gauging station on the Powder River at Moorhead, Montana.

This analysis assumed that Montana Preferred Alternative E would be adopted. Under Alternative E, Montana would not allow untreated surface discharge from CBM wells to the Middle Powder River sub-watershed (in other words, managed water losses would equal 100 percent) if Wyoming were to implement Alternative 1. Montana would, however, allow unlimited (100 percent) surface discharge, assuming MPDES permit requirements were met, if Wyoming were to implement one of Alternatives 2A, 2B, or 3. Results of the impact analysis for the Middle Powder river sub-watershed under each alternative are presented in Table 5-9. Potential impacts to water quality are discussed below.

Table 5-9
Surface Water Impact Analysis of the Middle Powder River Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
1	2.0	1000	10	3200	145	4.6	2154	312	13.8	2270	0.3	6.15	4400	167	21.8	2374
2A	2.0	1000	10	3200				230	11.6	2253				85	23.2	2426
2B	2.0	1000	10	3200				223	11.2	2249				78	23.3	2431
3	2.0	1000	10	3200				218	11.3	2270				73	24.4	2505

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.2.2.1 Alternative 1

Under Alternative 1, the peak of water production in the Middle Powder River sub-watershed would occur in year 2005, when 21,047 wells would be producing at an average rate of 6.2 gpm per well. The peak year of water production in the Salt Creek, Clear Creek, Crazy Woman Creek, and Upper Powder River sub-watersheds would occur in 2006; however, this analysis used the number of wells that would be producing in those watersheds during 2006 for the analysis of cumulative impacts in the Middle Powder River sub-watershed for 2005 to predict the impacts during the peak year. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Middle Powder River sub-watershed during the peak year of CBM water production is about 167 cfs (120,920 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC and SAR values in the Middle Powder River currently exceed the MRPL for both constituents under low mean monthly and 7Q10 flow conditions. With the exception of the EC under 7Q10 flow conditions, the water quality currently is less than the LRPL for both EC and SAR under similar flow conditions. After the water mixes, natural stream flow would increase by approximately twofold during low-flow conditions. The resultant EC and SAR would increase from existing conditions. The resulting stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Middle Powder River sub-watershed would not meet the MRPL for both EC and SAR during all months and during 7Q10 flow conditions.
- LRPL: The resultant water quality would be adequate to meet the LRPL for EC during all months of the year but would not be adequate to meet the LRPL for SAR during the lowest flow months, or during 7Q10 flow conditions. The lowest flow months include the irrigation season from August through October.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates that there would not be a reduction in infiltration except during 7Q10 flow conditions. During the low monthly flow, essentially all of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Based on modeled results, impacts to the suitability for irrigation of the Middle Powder River from CBM development in Wyoming and Montana would be expected to occur at the Moorhead, Montana station, using the MRPL and LRPL criteria if the states and EPA conclude that the proposed limits would be protective of irrigation uses.

Modeling indicates that the suitability of the Powder River for irrigation may be compromised by surface discharge of CBM produced water during maximum CBM development in both states. However, enhanced monitoring of CBM discharges and an evaluation of downstream irrigation practices would be necessary to assess whether there would be a measurable decrease in crop production. State permitting procedures in Wyoming require CBM operators to include an irrigation use protection plan with the NPDES permit application that specifies necessary measures to prevent violating the narrative standards for protection of irrigated agriculture in the Powder River drainage. Mitigation measures would be implemented based on the site-specific analysis of existing irrigation practices. CBM operators could be required to increase the amount of storage of CBM water during the irrigation months, and proceed with more surface discharge during the non-irrigation months, to meet the needs of downstream irrigators. As the state develops a better understanding of the effects of CBM discharges through the enhanced monitoring required by the MOC, Wyoming can adjust its permitting approach to allow more or less discharges to the Powder River drainage. Through the implementation of instream monitoring and adaptive management, water quality standards and agreements with bordering states can be met.

5.2.2.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and lowered surface discharge. Under modeled conditions, the amount of produced water that is assumed to reach the main stem of the Middle Powder River sub-watershed during the peak year of CBM water production is about 86 cfs (62,270 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After the water mixes, the resultant flow under low monthly flow conditions would increase slightly. The resultant EC and SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-29 and 5-30 illustrate the months during the year when the existing water quality and resultant quality of mixed water under mean monthly flow and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Middle Powder River sub-watershed. Under modeled conditions, the resultant water quality under mean monthly and 7Q10 flow conditions is greater than the MRPL for EC and SAR during all months of the year when CBM produced water discharges from both states are mixed.
- LRPL: Under modeled conditions, the resultant EC is less than the LRPL under similar flow conditions when CBM produced water discharges from both states are mixed. The resultant SAR would not be adequate to meet the LRPL during the lowest flow months or during 7Q10 flow.
- Ayers and Westcot diagram: Figure 5-31 illustrates the suitability for irrigation of the Powder River before and after the river mixes with discharges of CBM produced water. Under modeled conditions, a comparison of the resultant mixed water quality with the Ayers-Westcot diagram in Figure 5-31 indicates that a reduction in infiltration is not likely except under 7Q10 flow conditions. Figure 5-32 illustrates the relationship between EC and SAR in the Middle Powder River sub-watershed after the river mixes with varying proportions of CBM produced water discharges under various stream flow conditions. Under modeled conditions, essentially all of the CBM discharge to the Middle Powder River sub-watershed from both states could occur without causing effects to infiltration, with the exception of 7Q10 flow conditions. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Based on modeled results, under certain flow conditions, impacts to irrigated agriculture in the Powder River sub-watershed from CBM development in Wyoming and Montana under Alternative 2A may occur. Although the resultant impacts fall outside the boundaries of the LRPL during some months, BLM recognizes the uncertainty concerning the determination of water quality standards for EC and SAR. If a standard at the low end of the range of proposed values is selected, additional mitigation may be necessary for CBM discharges to this sub-watershed to occur. Potential mitigation measures that could be implemented in order to meet the ultimate regulatory standards for EC and SAR once those standards have been identified include CBM produced water storage during the irrigation months and surface discharge during the non-irrigation months. In addition, discharge permits issued by the WDEQ and MDEQ will be the mechanism that will identify the appropriate mix of water handling methods to be employed to meet the standards. As a result, even though the model predicts impacts, ultimately those predicted impacts to the irrigation suitability of the Powder River from CBM development in Wyoming and Montana under Alternative 2A may not occur.

Figure 5-29 Stream EC Before and After Mixing- Middle Powder River Sub-Watershed

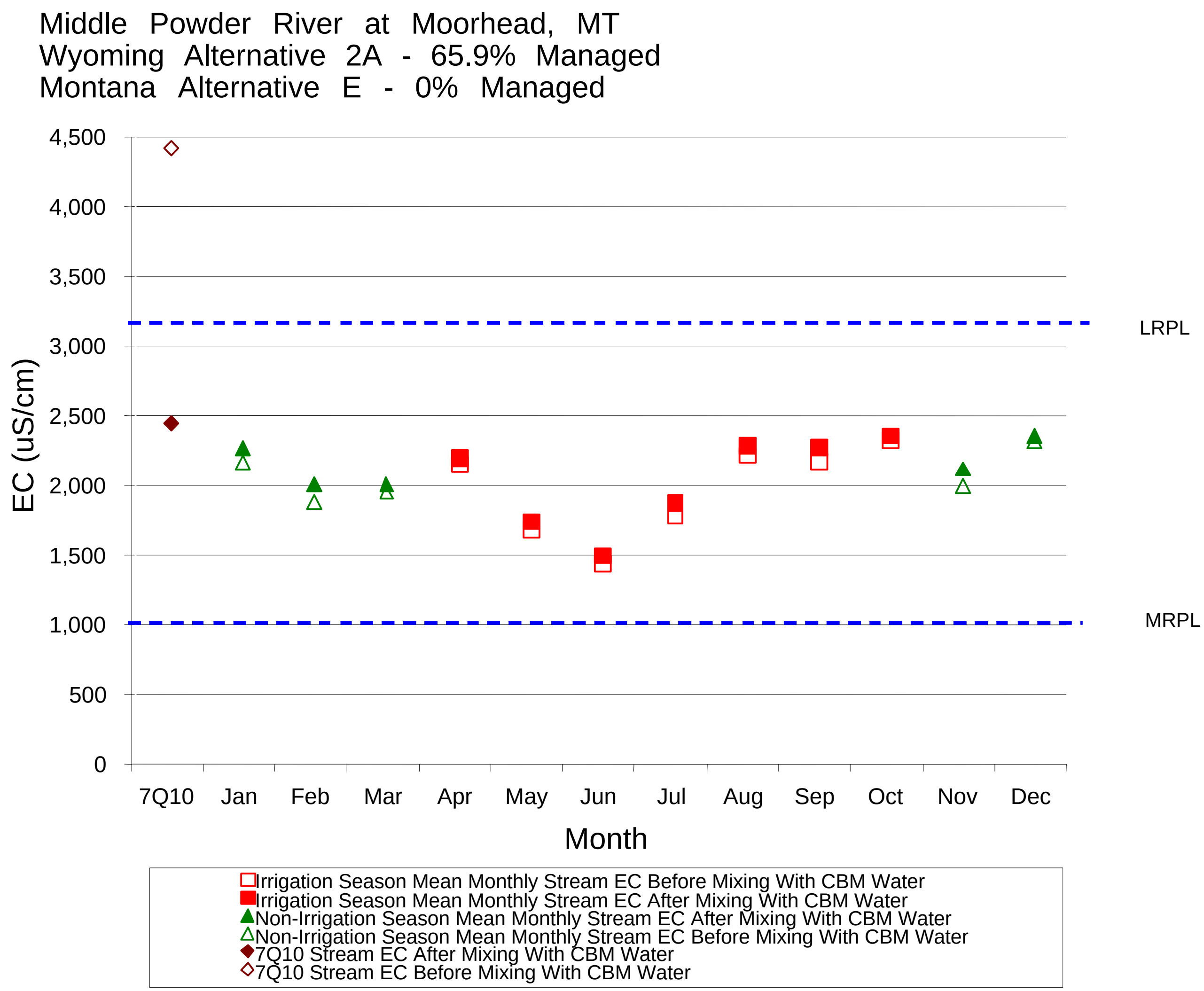


Figure 5-30 Stream SAR Before and After Mixing- Middle Powder River Sub-Watershed

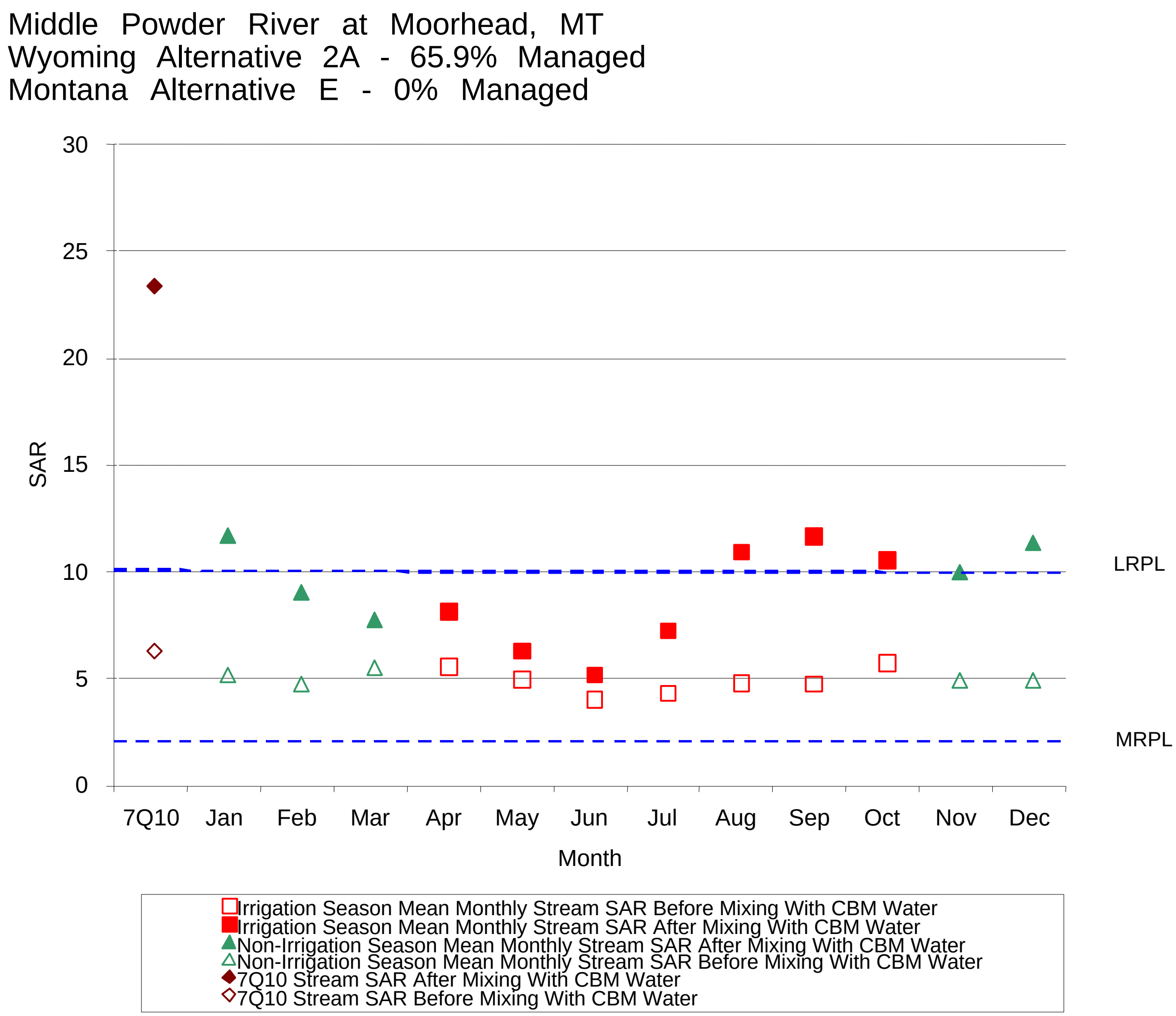


Figure 5-31 Irrigation Suitability Before and After Mixing – Middle Powder River Sub-Watershed

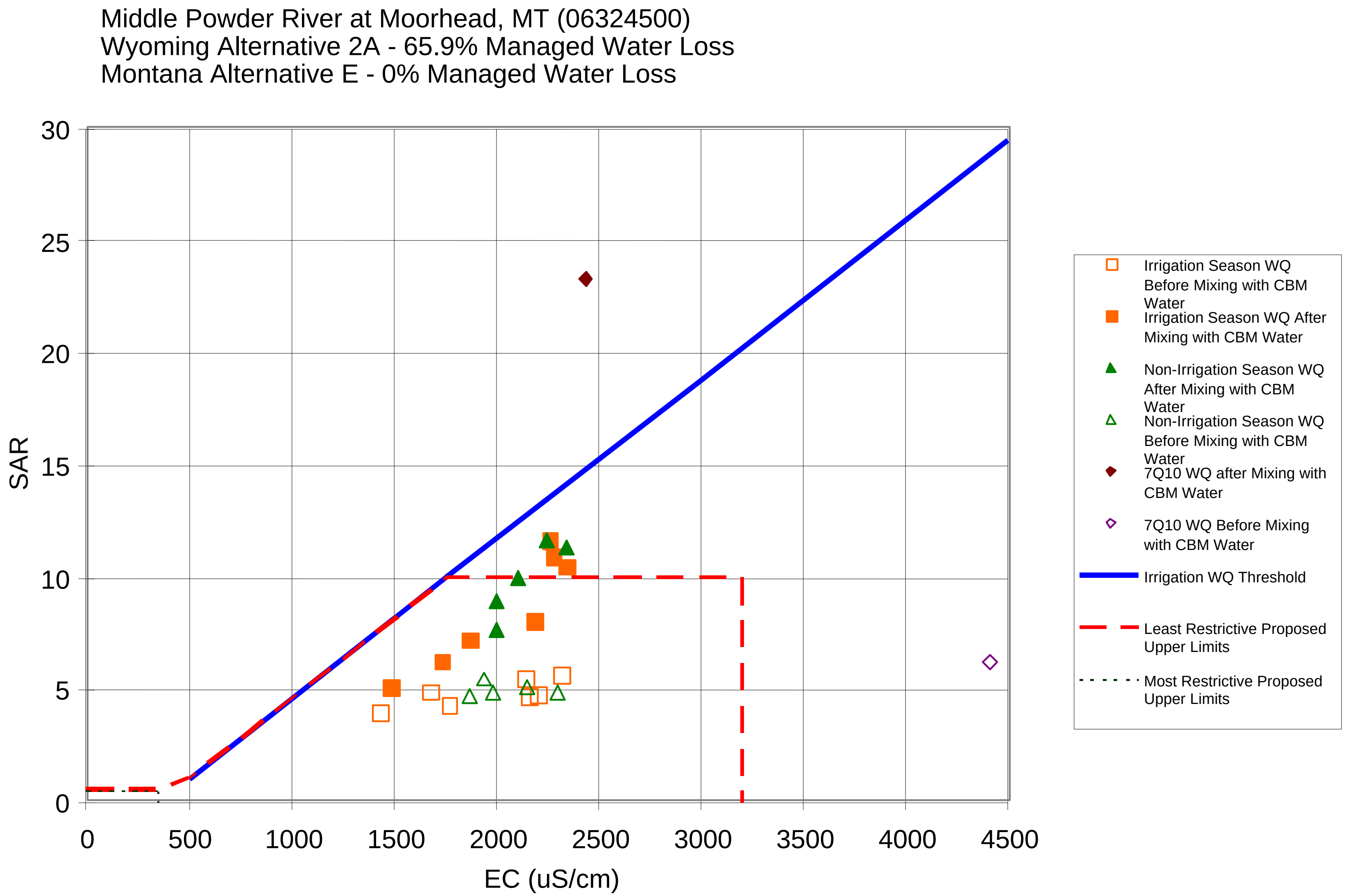
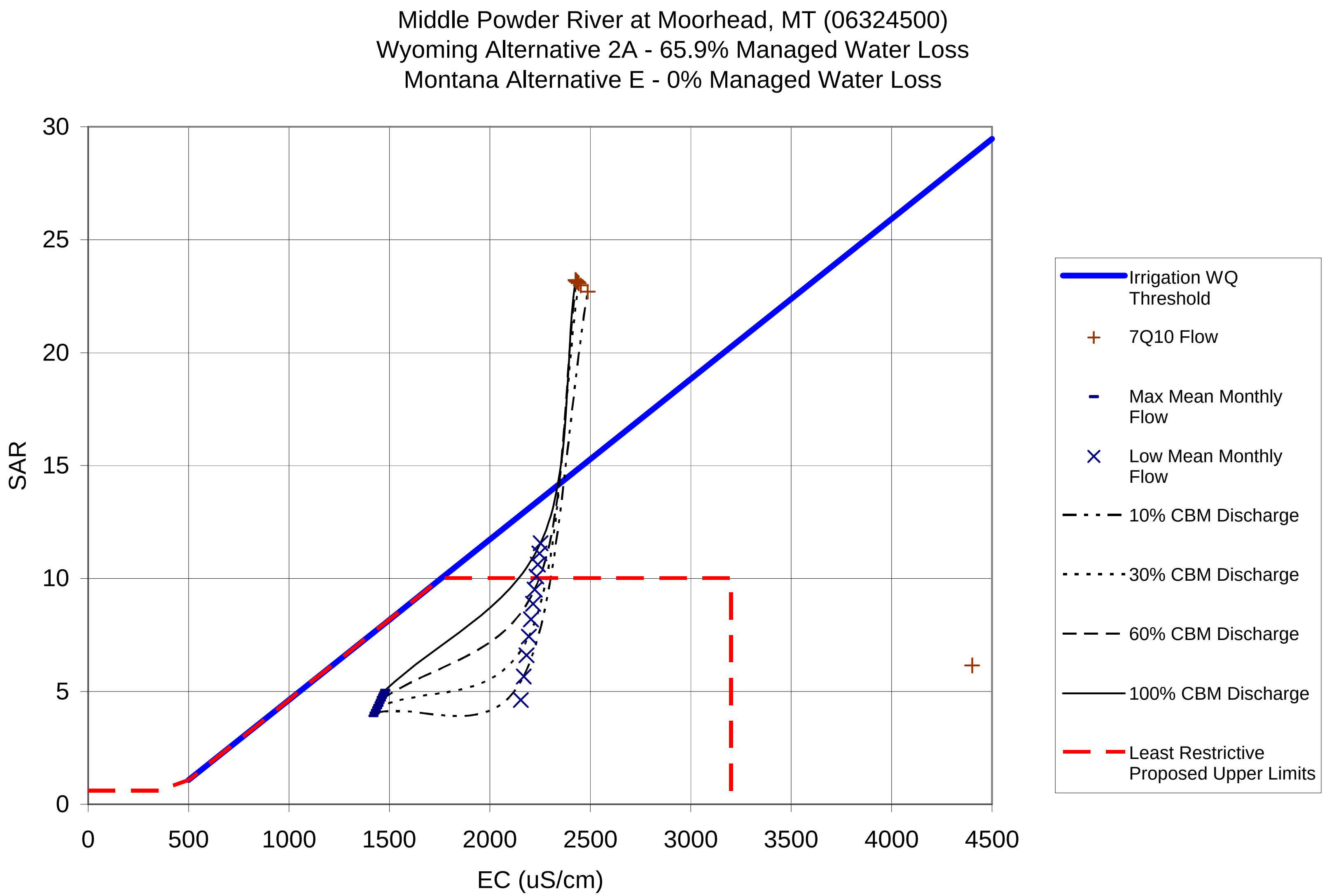


Figure 5-32 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Middle Powder River Sub-Watershed



5.2.2.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and implementation of active treatment. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Middle Powder River sub-watershed during the peak year of CBM water production is about 79 cfs (57,200 acre-feet per year). Impacts to surface water quality in the Middle Powder River sub-watershed would be less than were described under Alternative 1, and similar to those described for Alternative 2A. Additional water would be available to support beneficial use because of the proportion of water that would undergo active treatment.

5.2.2.4 Alternative 3

Under Alternative 3, the peak of water production in the Middle Powder River sub-watershed would occur in year 2005, when 8,469 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Middle Powder River sub-watershed during the peak year of CBM water production is about 74 cfs (53,581 acre-feet per year). Impacts to the quality of surface water in the Middle Powder River sub-watershed would be similar to Alternative 1.

5.2.3 Little Powder River

Development of CBM resources in Montana would not contribute flows upstream of the USGS gauging station on the Little Powder River near Weston, Wyoming. However, CBM development in Wyoming has the potential to cause impacts to water quality in this drainage. Therefore, future forecast development of CBM resources downstream in Montana may be limited in the amount of surface discharge to this drainage under the Montana preferred alternative.

Results of the impact analysis in the Little Powder River sub-watershed under each alternative are presented in Table 5-10. Potential water quality impacts are discussed below.

Table 5-10
Surface Water Impact Analysis of the Little Powder River Sub-Watershed

Alternative	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
	SAR	EC (μS/cm)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)
1	3.0	1000	10	3000	3	6.9	3300	21	10.6	1519	0.0	--	--	18	11.1	1271
2A	3.0	1000	10	3000				16	10.4	1606				13	11.1	1271
2B	3.0	1000	10	3000				15	10.4	1625				12	11.1	1271
3	3.0	1000	10	3000				18	10.5	1564				15	11.1	1271

Notes:
MRPL = Most restrictive proposed limit
LRPL= Least restrictive proposed limit
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
μS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.2.3.1 Alternative 1

Under Alternative 1, the peak of water production in the Little Powder River sub-watershed would occur in year 2005, when 2,543 wells would be producing at an average rate of 6.2 gpm per well. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Little Powder River sub-watershed during the peak year of CBM water production is about 19 cfs (13,757 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

Mean monthly EC and SAR values in the Little Powder River currently exceed the MRPL for both constituents under low mean monthly and 7Q10 flow conditions. Mean EC and SAR values currently are less than the LRPL for both constituents, except during low-flow conditions. After the water mixes, the resultant stream flow under low-flow conditions would increase. The resultant EC would decrease, whereas the SAR would increase from existing conditions. The existing 7Q10 flow is calculated as zero. Therefore, the resultant water quality under these flow conditions would be represented by the quality of CBM produced water, if discharges were to occur during critical low-flow periods. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Little Powder River during all months and during 7Q10 flow conditions would not meet the MRPL for both EC and SAR.
- LRPL: The resultant water quality would be adequate to meet the LRPL for EC during all months of the year but would not be adequate to meet the LRPL for SAR during the lowest flow months. These low-flow months include the irrigation season during August and September.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates that there would be some reduction in infiltration during some months of the irrigation season and during 7Q10 flow conditions. During the low monthly flow, about 40 percent of the CBM discharge could occur without causing potential effects to infiltration.

Based on modeled results, under certain flow conditions, impacts to the suitability for irrigation of the Little Powder River from CBM development in Wyoming would be expected to occur at the Weston, Wyoming station using the Ayers-Westcot diagram and MRPL and LRPL criteria for EC and SAR, if the states and EPA conclude that the proposed limit would be protective of irrigation uses.

Modeling indicates that the suitability of the Little Powder River for irrigation may be compromised by the surface discharge of CBM produced water during maximum CBM development in both states. However, enhanced monitoring of CBM discharges and an evaluation of downstream irrigation practices would be necessary to assess whether there would be a measurable decrease in crop production. State permitting procedures in Wyoming require CBM operators to include an irrigation use protection plan with the NPDES permit application that specifies measures necessary to prevent violations of the narrative standards for protection of irrigated agriculture in the Powder River drainage. Mitigation measures would be implemented based on the site-specific analysis of existing irrigation practices. CBM operators could be required to increase the amount of storage of CBM water during the irrigation months, and proceed with more surface discharge during the non-irrigation months, to meet the needs of downstream irrigators. As the state develops a better understanding of the effects of CBM discharges through the enhanced monitoring required by the MOC, Wyoming can adjust its permitting approach to allow more or less discharges to the Little Powder River drainage so that water quality standards and agreements with bordering states can be met.

5.2.3.2 Alternative 2A

Under Alternative 2A, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and lowered surface discharge. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Little Powder River sub-watershed during the peak year of CBM water production is about 13 cfs (9,143 acre-feet per year). The volume of water production would be less in other than the peak year, and modeled impacts would correspond to this reduction.

After the water mixes, the resultant flow under low monthly flow conditions would increase slightly. The resultant EC and SAR would increase from existing conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Figures 5-33 and 5-34 are used to illustrate the months during the year when the existing water quality and resultant mixed water quality under mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL being considered for water quality in the Little Powder River sub-watershed. Under modeled conditions, the resultant water quality under mean monthly and 7Q10 flow conditions is greater than the MRPL for EC and SAR during all months of the year.
- LRPL: Under modeled conditions, the resultant EC is less than the LRPL under both mean monthly and 7Q10 flow conditions. The resultant SAR is less than the LRPL, except during the lowest flow months, and during 7Q10 flow.
- Ayers and Westcot diagram: Figure 5-35 illustrates the suitability for irrigation of the Little Powder River before and after the river mixes with discharges of CBM produced water under Wyoming's Alternative 2A. Under modeled conditions, a comparison of the resultant quality of the mixed water with the Ayers-Westcot diagram in Figure 5-35 indicates that there would be some reduction in infiltration during some months of the irrigation season and under 7Q10 flow conditions. Figure 5-36 illustrates the relationship between EC and SAR in the Little Powder River after the river mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, about 50 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Based on modeled results, under certain flow conditions, impacts to the suitability for irrigation of the Little Powder River from CBM development may occur. However, as noted previously, samples collected since the onset of CBM production in the Upper Belle Fourche River and Little Powder River sub-watersheds have not detected changes in ambient stream water quality which were predicted by the mass balance model, and actual impacts may be less then the mass balance model predicts. The magnitude of the model results can not be verified based upon actual measured water quality data. Adequate protection of existing uses and water quality standards can only be accomplished through direct monitoring of stream water quality to measure the effects of CBM discharge. In addition, discharge permits issued by the WDEQ will be the mechanism that will identify the appropriate mix of water handling methods to be employed to meet the standards. As a result, even though the model predicts impacts, ultimately those predicted impacts to the irrigation suitability of the Little Powder River from CBM development in Wyoming under Alternative 2A may not occur.

Figure 5-33 Stream EC Before and After Mixing-Little Powder River Sub-Watershed

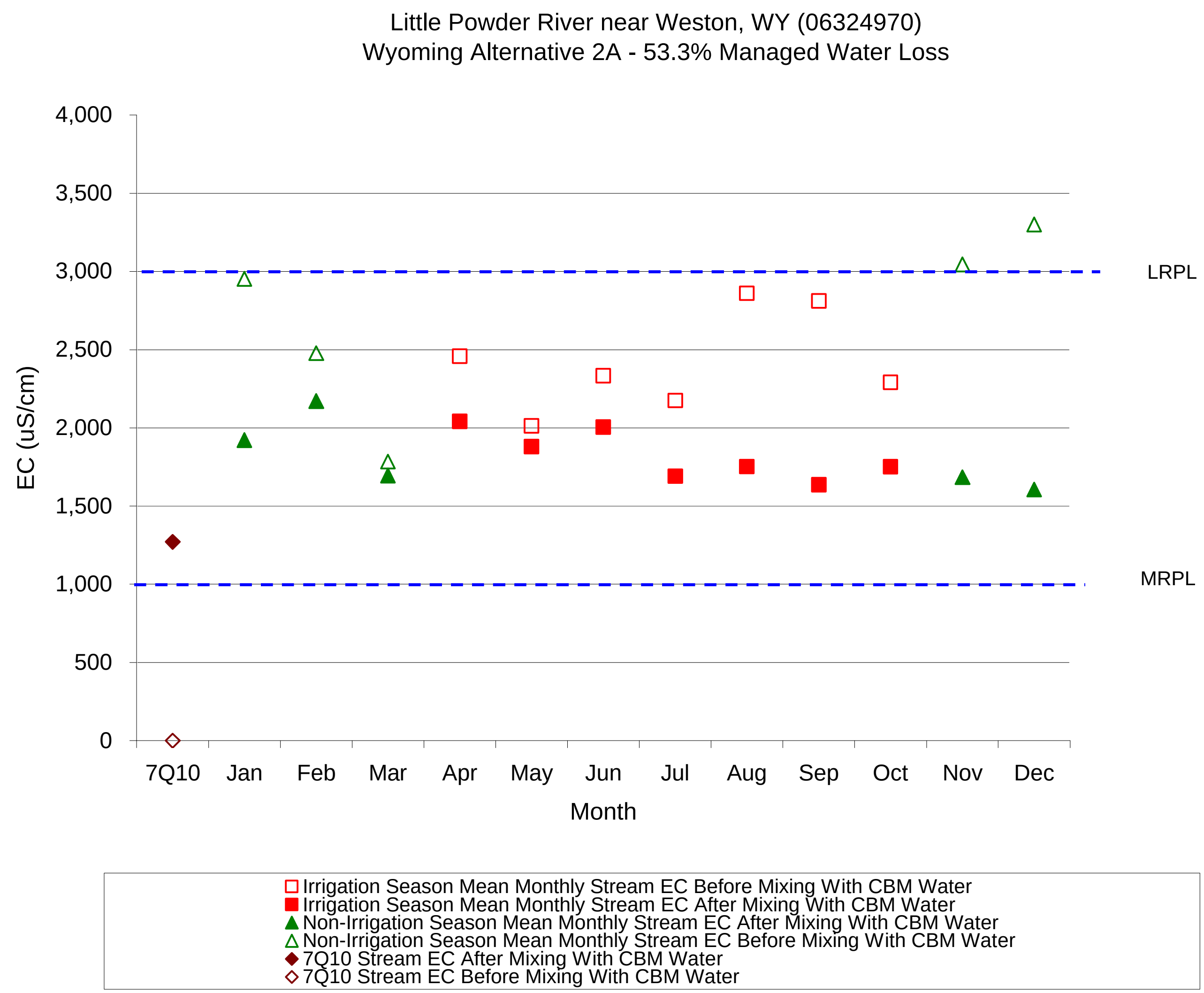


Figure 5-34 Stream SAR Before and After Mixing-Little Powder River Sub-Watershed

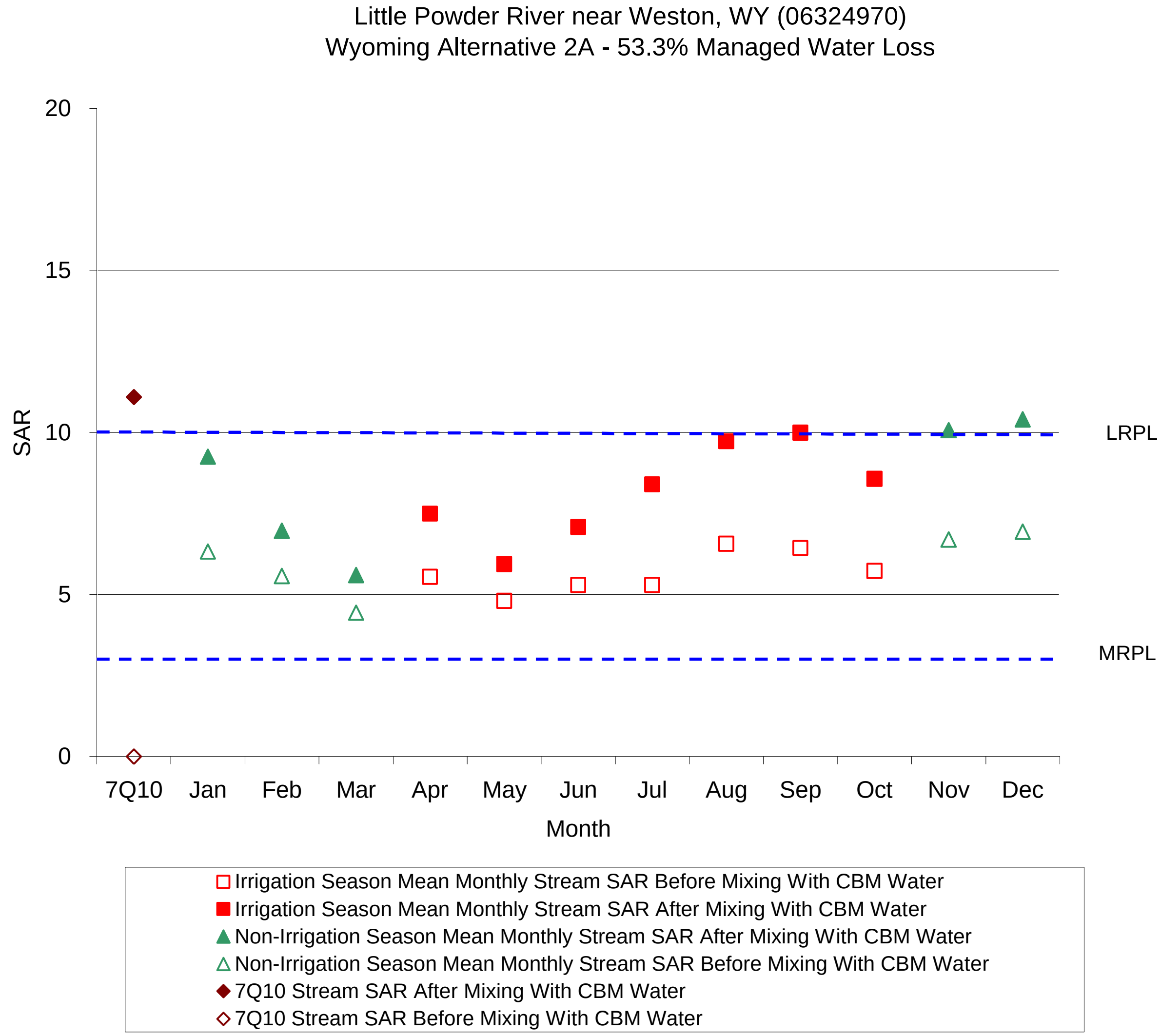


Figure 5-35 Irrigation Suitability Before and After Mixing - Little Powder River Sub-Watershed

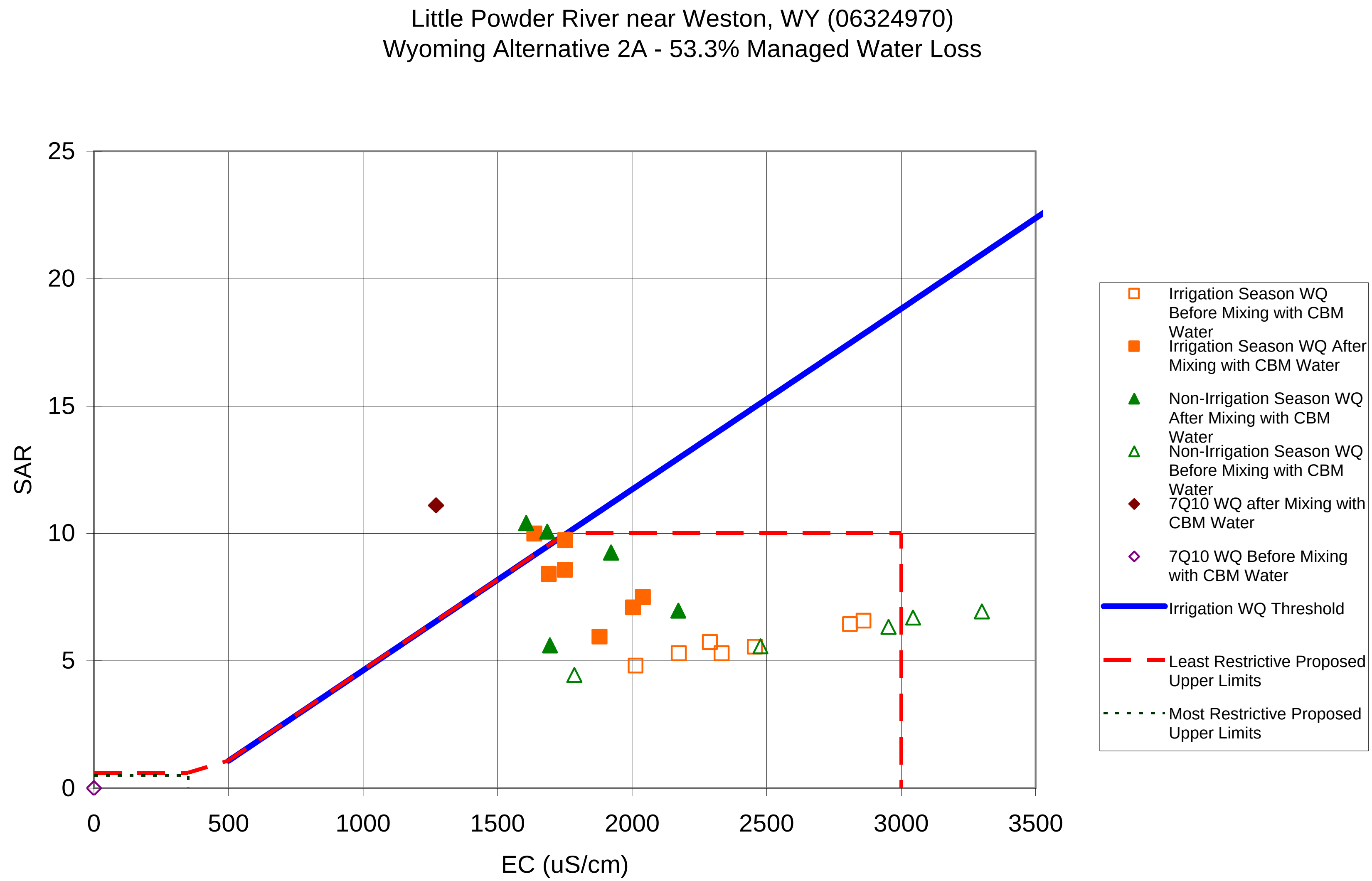
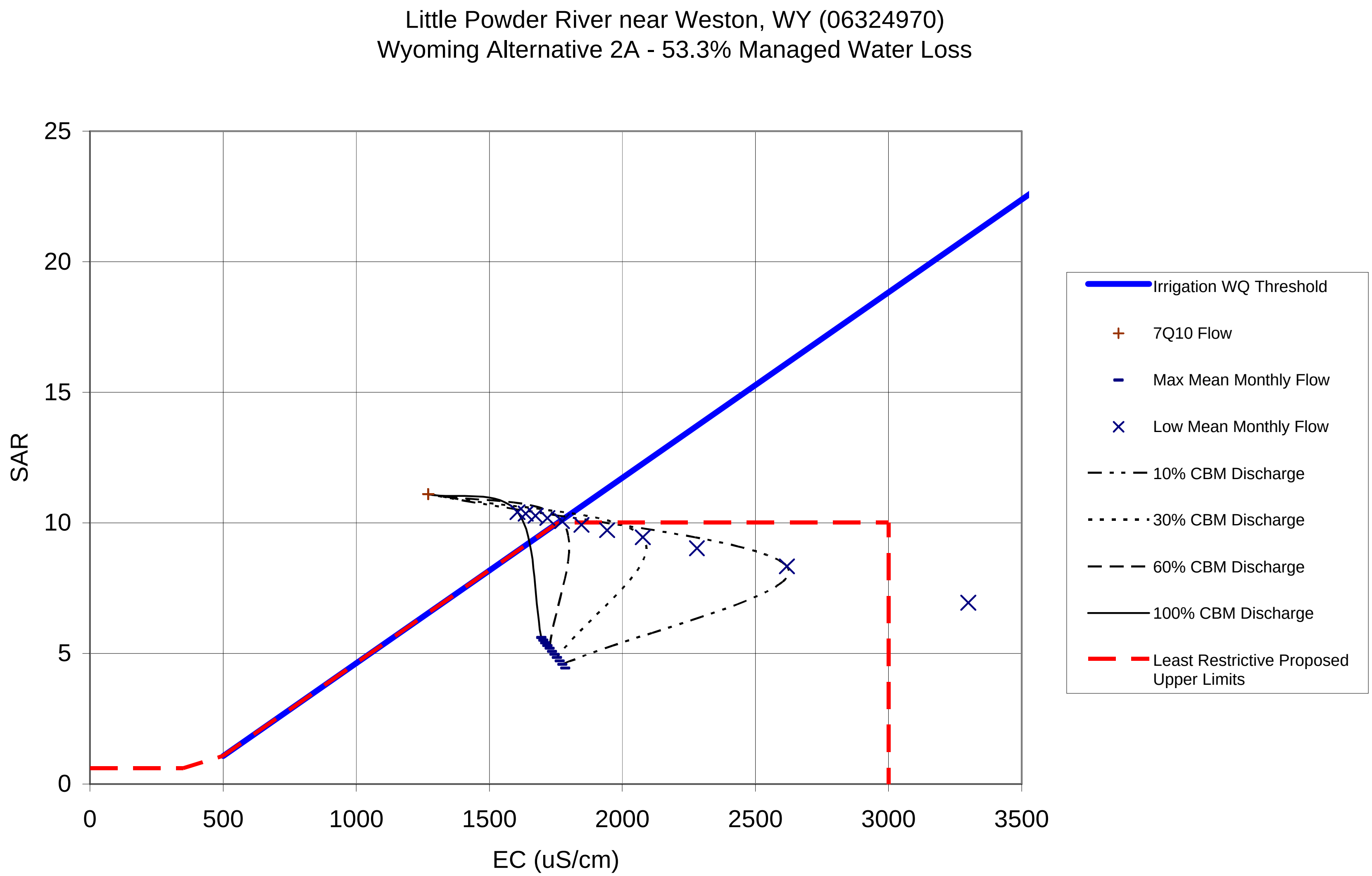


Figure 5-36 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Little Powder River Sub-Watershed



5.2.3.3 Alternative 2B

Under Alternative 2B, the peak year of water production and the water produced from CBM wells would be the same as under Alternative 1. Managed water losses would be greater than under Alternative 1, primarily because of the increase in infiltration impoundments and implementation of active treatment. Under modeled conditions, the amount of produced water that is assumed to reach the main stem of the Little Powder River sub-watershed during the peak year of CBM water production is about 12 cfs (8,689 acre-feet per year). Impacts to surface water quality in the Little Powder River sub-watershed would be less than were described under Alternative 1, and similar to those described for Alternative 2A. Additional water would be available to support beneficial use because of the proportion of water that would undergo active treatment.

5.2.3.4 Alternative 3

Under Alternative 3, the peak of water production in the Little Powder River sub-watershed would occur in year 2005, when 2,093 wells would be producing at an average rate of 6.2 gpm per well. Managed water losses would be the same as under Alternative 1. Under modeled conditions, the amount of produced water assumed to reach the main stem of the Little Powder River sub-watershed during the peak year of CBM water production is about 15 cfs (10,861 acre-feet per year). Impacts to surface water quality in the Little Powder River sub-watershed would be similar to Alternative 1.

5.3 Montana Streams

Potential impacts to the water quality in Montana streams were analyzed assuming Wyoming Alternative 2A would be implemented and potential impacts to water quality identified from CBM development under Alternative 2A in Wyoming would persist in Montana. Potential water quality impacts identified in Wyoming streams that flow into Montana were assumed to be present under all five management alternatives considered in the Montana FEIS.

5.3.1 Tongue River

The headwaters of the Tongue River are in the Bighorn Mountains southwest of the point where it crosses the state line near Decker, Montana; it can receive CBM discharges from current and future development in both the Wyoming and Montana portions of the PRB. Table 5-11 below summarizes the impacts for the three stream stations along the Tongue River in Montana.

The Tongue River is not expected to be affected by direct discharges of CBM produced water from Wyoming based on WDEQ's "no new discharge" policy. It was assumed, however, that 15 percent of the Managed Water Loss from CBM discharges in Wyoming would reach the Tongue River and contribute to existing surface flows before it reaches the state line station. Additional impacts to water quality could be anticipated from the surface discharge of 240 CBM wells in the CX Ranch field, as well as additional CBM wells under other management alternatives.

Table 5-11
Surface Water Impact Analysis of the Upper/Lower Tongue River Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
A	Tongue R at Stateline Near Decker, MT	0.5	500	10	2500	178	0.86	731	183	1.93	773	43	1.29	1179	48	5.34-5.09	1295-1304
	Tongue R at Birney Day School Near Birney, MT	0.5	500	10	2500	183	1.09	863	190	2.52	912	45	1.60	1159	51	6.26-6.79	1316-1303
	Tongue R below Brandenberg Bridge Near Ashland, MT	0.5	500	10	2500	207	1.36	1016	214	2.50	1058	70	1.82	1281	76	4.95-5.31	1377-1368
C	Tongue R at Stateline Near Decker, MT	0.5	500	10	2500	178	0.86	731	187	2.68-2.94	806-812	43	1.29	1179	52	7.76-8.70	1369-1391
	Tongue R at Birney Day School Near Birney, MT	0.5	500	10	2500	183	1.09	863	213	6.38-7.43	1055-1080	45	1.60	1159	75	16.43-19.4	1586-1658
	Tongue R below Brandenberg Bridge Near Ashland, MT	0.5	500	10	2500	207	1.36	1016	265	9.51-11.22	1278-1319	70	1.82	1281	128	18.49-22.04	1705-1790
D	Tongue R at Stateline Near Decker, MT	0.5	500	10	2500	178	0.86	731	187	1.49	747	43	1.29	1179	52	3.46	1157

Table 5-11
Surface Water Impact Analysis of the Upper/Lower Tongue River Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
	Tongue R at Birney Day School Near Birney, MT	0.5	500	10	2500	183	1.09	863	213	1.59	824	45	1.60	1159	75	6.79	1303
	Tongue R below Brandenberg Bridge Near Ashland, MT	0.5	500	10	2500	207	1.36	1016	265	1.67	904	70	1.82	1281	128	2.26	929
E	Tongue R at Stateline Near Decker, MT	0.5	500	10	2500	178	0.86	731	183	1.93	773	43	1.29	1179	48	5.34	1295
	Tongue R at Birney Day School Near Birney, MT	0.5	500	10	2500	183	1.09	863	190	2.52	912	45	1.60	1159	51	6.26-6.79	1303-1316
	Tongue R below Brandenberg Bridge Near Ashland, MT	0.5	500	10	2500	207	1.36	1016	214	2.50	1058	70	1.82	1281	76	4.95-5.31	1368-1377

Notes:
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.3.1.1 Alternative A

Under this alternative, no further CBM development would occur, except at the existing CX Ranch field. Mean monthly EC and SAR values in the Tongue River at the three gauging stations currently exceed the MRPL for both constituents under low mean monthly and 7Q10 flow conditions. Mean EC and SAR values currently are less than the LRPL for both constituents under similar flow conditions. After the water mixes, the resultant flow under low monthly conditions would increase slightly at the three locations. The resultant EC and SAR would increase from existing stream conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Tongue River at the three locations would not be adequate to meet the MRPL for both EC and SAR; therefore, the Tongue River could not receive additional CBM discharges if the limits under consideration were adopted. The impacts forecast would further exceed these limits.
- LRPL: Under modeled conditions, the resulting water quality would be adequate to meet the LRPL for EC and SAR during the minimum mean monthly and 7Q10 flow conditions.
- Ayers and Westcot diagram: Irrigation with the mixed water indicates that no reduction in infiltration would be likely during the irrigation season. Essentially 100 percent of the CBM discharge could occur without causing potential effects to infiltration during the low monthly flow. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

5.3.1.2 Alternative C

Under this alternative, CBM discharges from maximum development would result in moderate increases in EC and flow and significant increases in SAR. The resultant stream water quality can be compared with the following criteria:

- MRPL: Under modeled conditions, the resultant water quality in the Tongue River at the three locations would not be adequate to meet the MRPL for both EC and SAR; therefore, the Tongue River could not receive additional CBM discharges if the limits under consideration were adopted. The forecast impacts from CBM discharges in Wyoming and Montana would further exceed these limits.
- LRPL: Under modeled conditions, the resultant water quality during the minimum mean monthly flow would exceed the LRPL for SAR at the Ashland station in Montana. The resultant water quality during other months would be below the proposed limits for both constituents. The resultant water quality during the 7Q10 flow would exceed the LRPL for SAR.
- Ayers and Westcot diagram: Irrigation with the mixed water at the station in Decker, Wyoming, indicates that there would not be a reduction in infiltration, except during 7Q10 flow conditions. The resultant water quality at the Birney Day School and Ashland stations would result in some reduction in infiltration. Texture and permeability, especially of clayey soils, could be reduced if the mixed Tongue River water from these locations were to be used for irrigation. Although this is a legal option, so long as a CBM producer were granted a permit to degrade surface waters by the MDEQ, such as an action would be contrary to the current policy of MDEQ, and the EPA. Irrigators may need to alter management schemes to avoid these impacts.

Under this alternative, the surface water quality of the Tongue River would be reduced, requiring changes in irrigation management practices by downstream users during part or all of the year. Although this is a legal option, so long as a CBM producer were granted a permit to degrade surface waters by the MDEQ, such as an action would be contrary to the current policy of MDEQ, and the EPA.

5.3.1.3 Alternative D

Under Alternative D, 20 percent of the produced water would be beneficially used, and the remaining 80 percent would be treated to achieve the pre-development quality of surface water before discharge.

The increases in surface water quality shown in Table 5-11 for Alternative D would result from the discharge of untreated CBM water from CBM development in Wyoming. The volume of flow would change as a result of treated and untreated discharges in both Montana and Wyoming. The effects to water quality that originate from Wyoming would be the same as were described under Alternative A. Effects on surface water conditions from CBM development in Montana would be caused by the increases in base flow.

5.3.1.4 Preferred Alternative E

Under Preferred Alternative E, the Tongue River could receive CBM discharges from current and future development in both the Wyoming and Montana portions of the PRB. The discharges forecast under this alternative would result in the same water quality described for Alternative A. The resultant stream water quality near Birney, Montana, can be compared with the following criteria:

- MRPL: Figures 5-37 and 5-38 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Upper Tongue River sub-watershed. This quality was modeled at the USGS gauging station near Birney, Montana. The water quality in the Tongue River near Birney naturally exceeds the MRPL for both EC and SAR for all but 2 months out of the average year; therefore, the Tongue River could not receive additional CBM discharges if the limits under consideration were adopted. The impacts forecast from CBM discharges in Wyoming and Montana would further exceed these limits.
- LRPL: The LRPL for EC and SAR would not be exceeded either during the minimum mean monthly or 7Q10 flow conditions.
- Ayers-Westcot diagram: Figure 5-39 illustrates the suitability for irrigation of the Upper Tongue River near Birney before and after the river mixes with discharges of CBM produced water. a comparison of the resultant mixed water quality with the Ayers-Westcot diagram in Figure 5-39 indicates that there would be some reduction in infiltration during some months of the irrigation season under modeled conditions. Figure 5-40 illustrates the relationship between EC and SAR in the Upper Tongue River near Birney after the river mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially 100 percent of the CBM discharge could occur during the low monthly flow and 7Q10 flow without causing effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Figure 5-37 Stream EC Before and After Mixing-Upper Tongue River Sub-Watershed

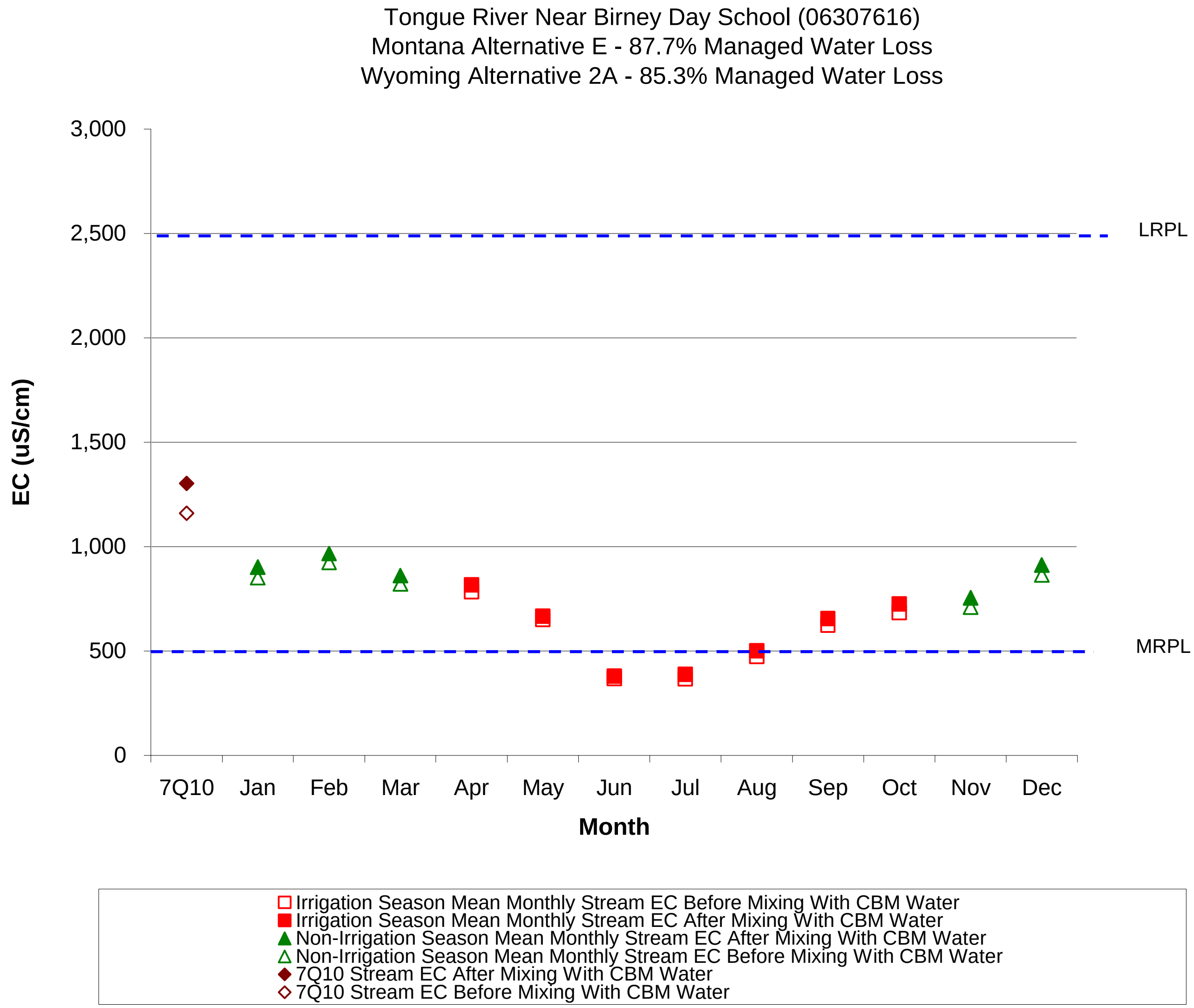


Figure 5-38 Stream SAR Before and After Mixing-Upper Tongue River Sub-Watershed

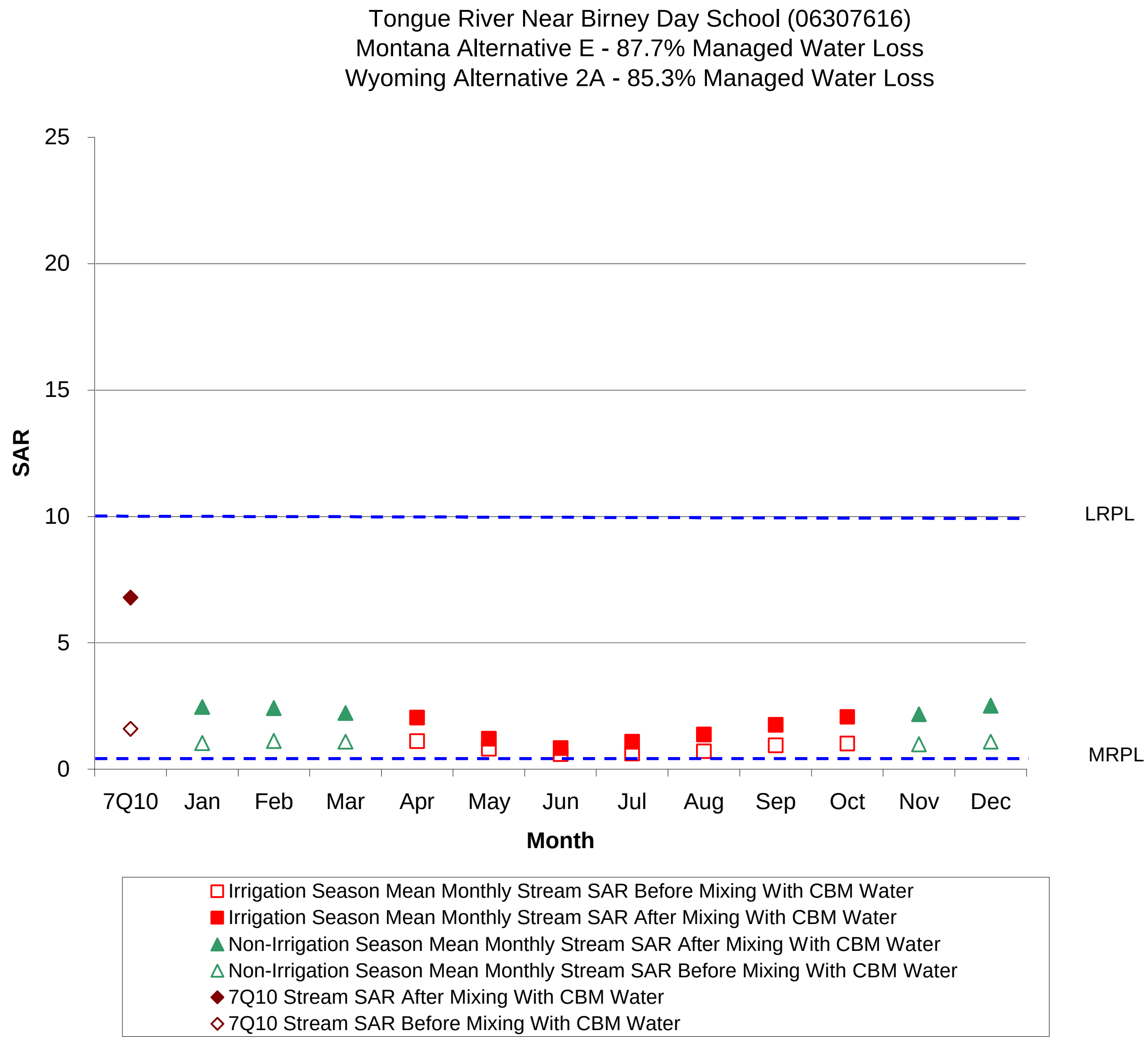


Figure 5-39 Irrigation Suitability Before and After Mixing – Upper Tongue River Sub-Watershed

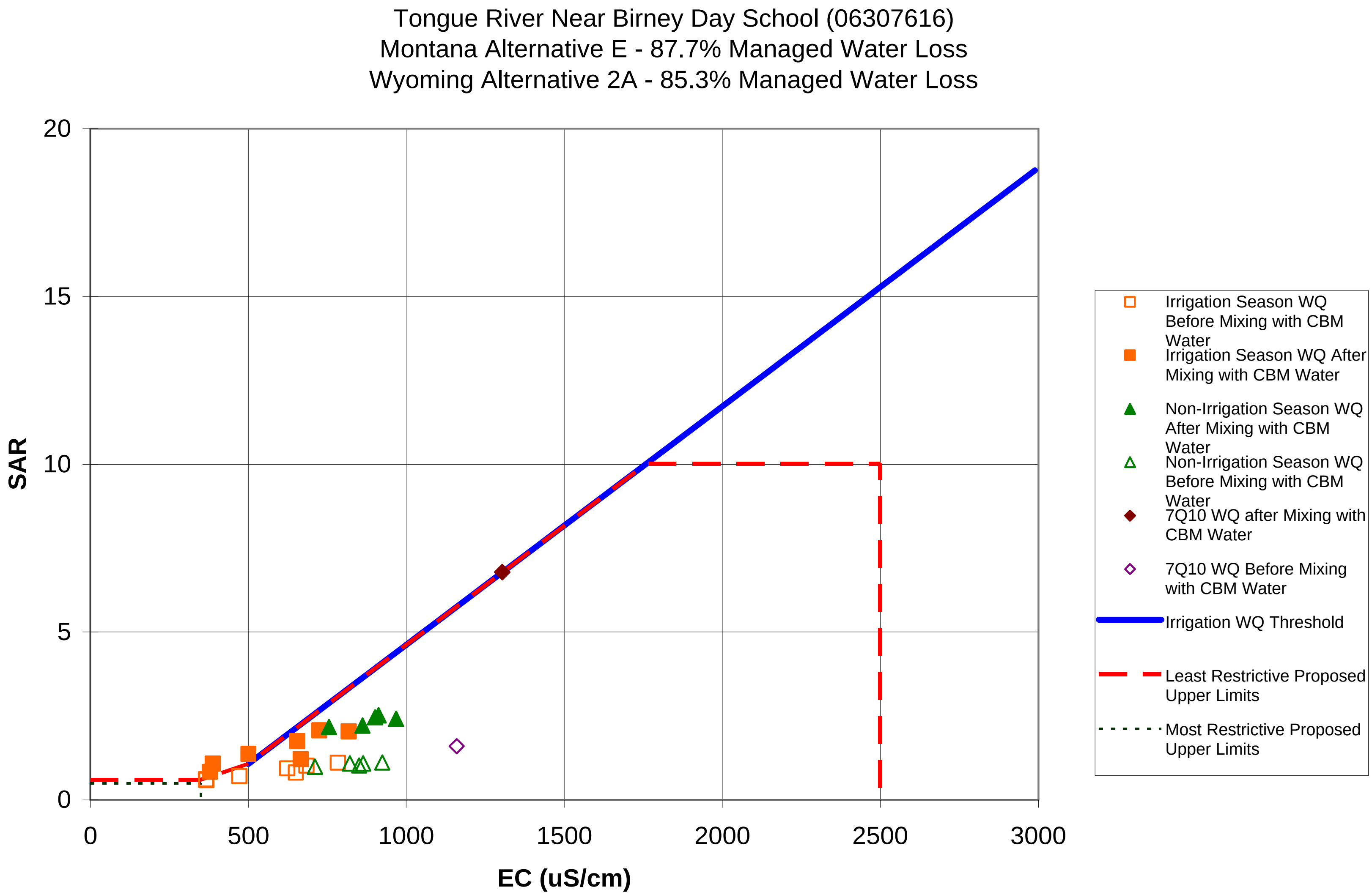
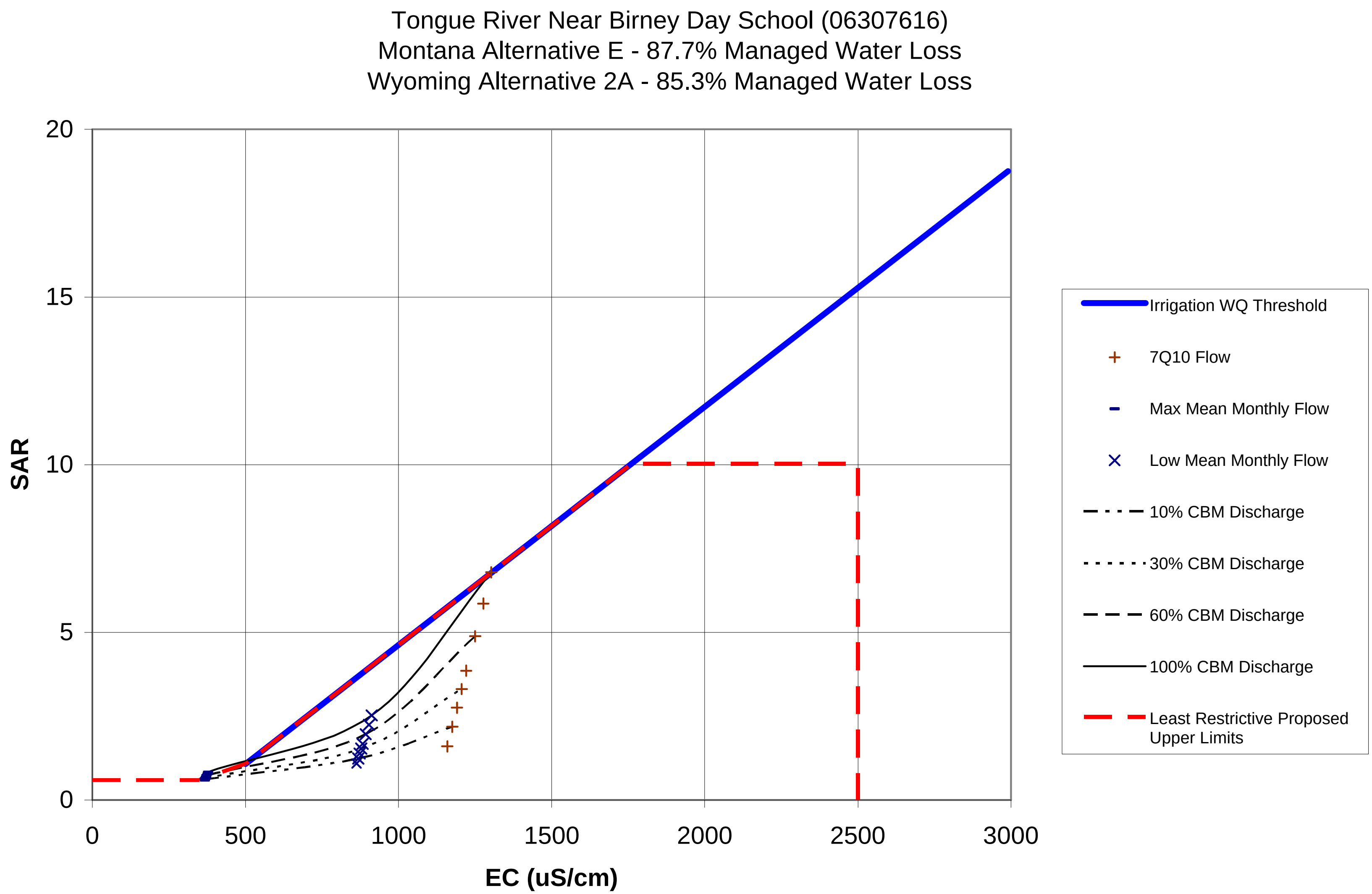


Figure 5-40 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Upper Tongue River Sub-Watershed



Under Alternative E, the resultant stream water quality near Ashland, Montana, can be compared with the following criteria:

- MRPL: Figures 5-41 and 5-41 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Upper Tongue River sub-watershed, as modeled at the USGS gauging station near Ashland, Montana. The water quality in the Tongue River near Ashland naturally exceeds the MRPL for both EC and SAR for all but 2 months out of the average year; therefore, the Tongue River could not receive additional CBM discharges if the limits under consideration were adopted. The impacts forecast from CBM discharges in Wyoming and Montana would further exceed these limits.
- LRPL: The LRPL for EC and SAR would not be exceeded either during the minimum mean monthly or 7Q10 flow conditions.
- Ayers-Westcot diagram: Figure 5-43 illustrates the suitability for irrigation of the Upper Tongue River near Ashland before and after the river mixes with discharges of CBM produced water.A comparison of the resultant mixed water quality with the Ayers-Westcot diagram in Figure 5-43 indicates that there would be some reduction in infiltration during some months of the irrigation season under modeled conditions. Figure 5-44 illustrates the relationship between EC and SAR in the Upper Tongue River near Ashland after the river mixes with varying proportions of Discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially 100 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

The Tongue River is an important source of irrigation water in the PRB. The effects to the Tongue River under this alternative would be the same as for Alternative A. No additional discharge from Montana to the Tongue River sub-watershed would be allowed under this alternative, except for discharge in accordance with the current CX Ranch MPDES permit. This permit currently allows a discharge of 3.3 cfs of CBM water. Of the 41 cfs of water predicted to be produced in year 6 of development, 3 cfs would be managed by surface discharge, and the remaining 38 cfs would need to be managed by other approved means.

Figure 5-41 Stream EC Before and After Mixing-Lower Tongue River Sub-Watershed

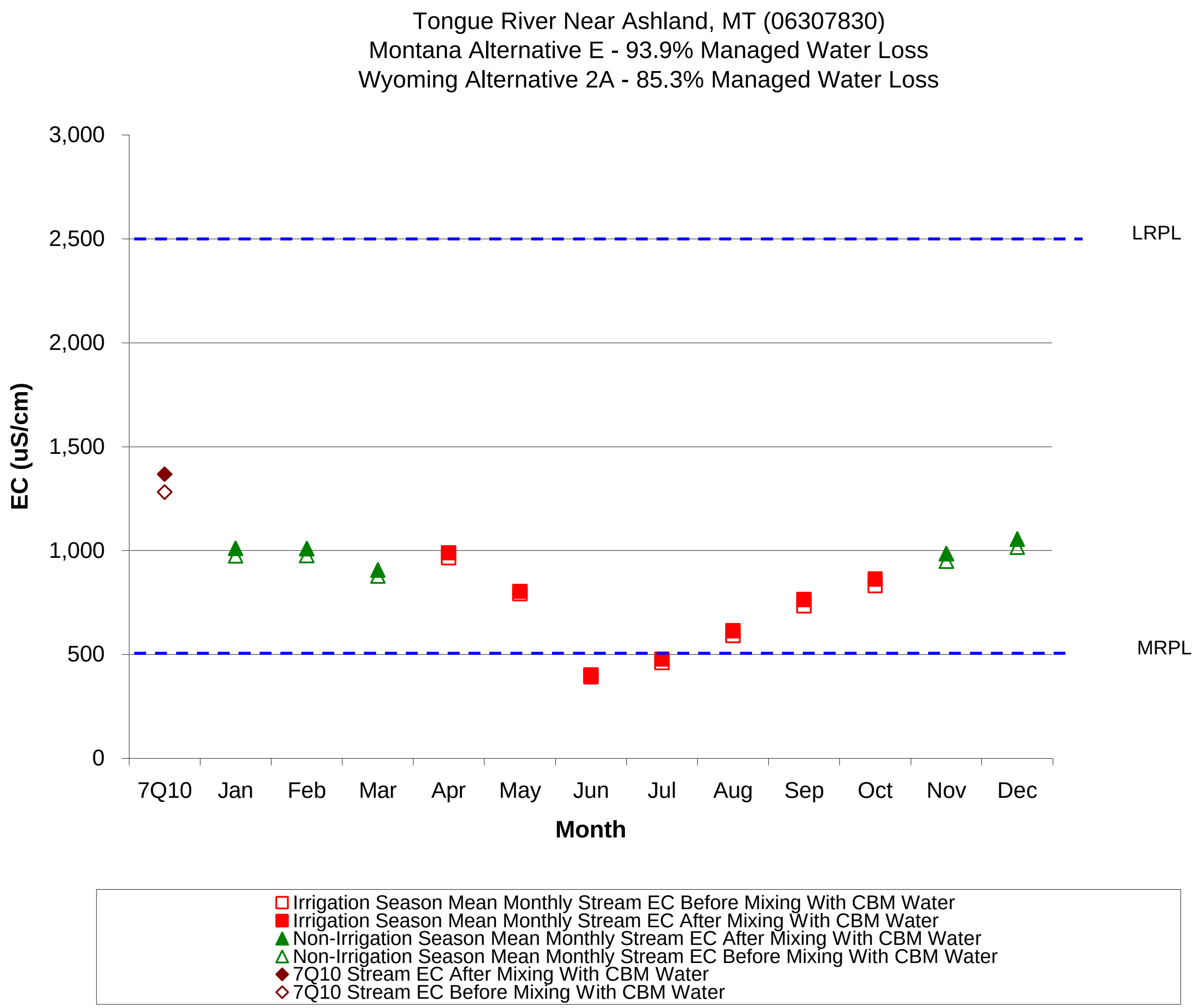


Figure 5-42 Stream SAR Before and After Mixing-Lower Tongue River Sub-Watershed

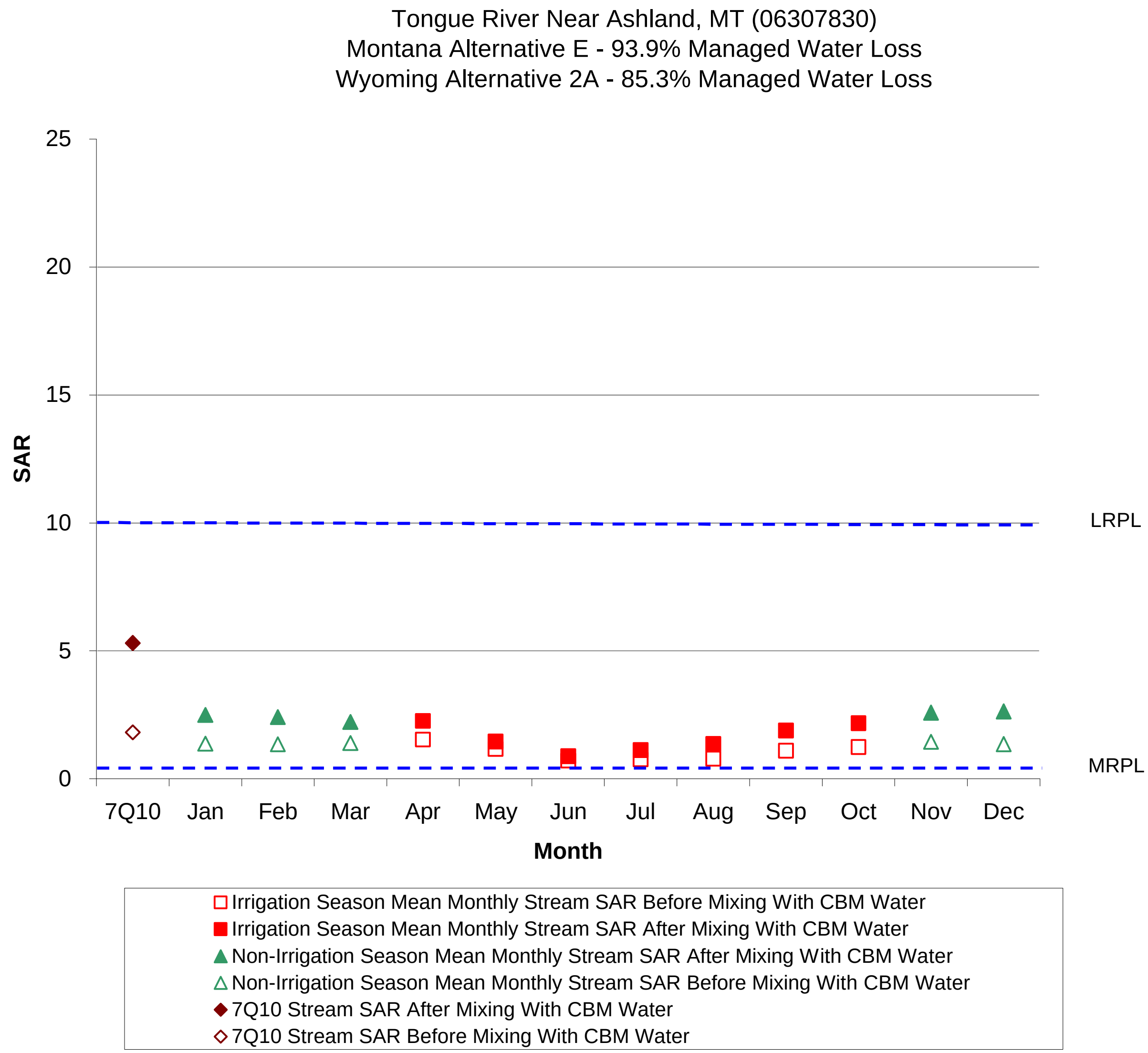


Figure 5-43 Irrigation Suitability Before and After Mixing – Lower Tongue River Sub-Watershed

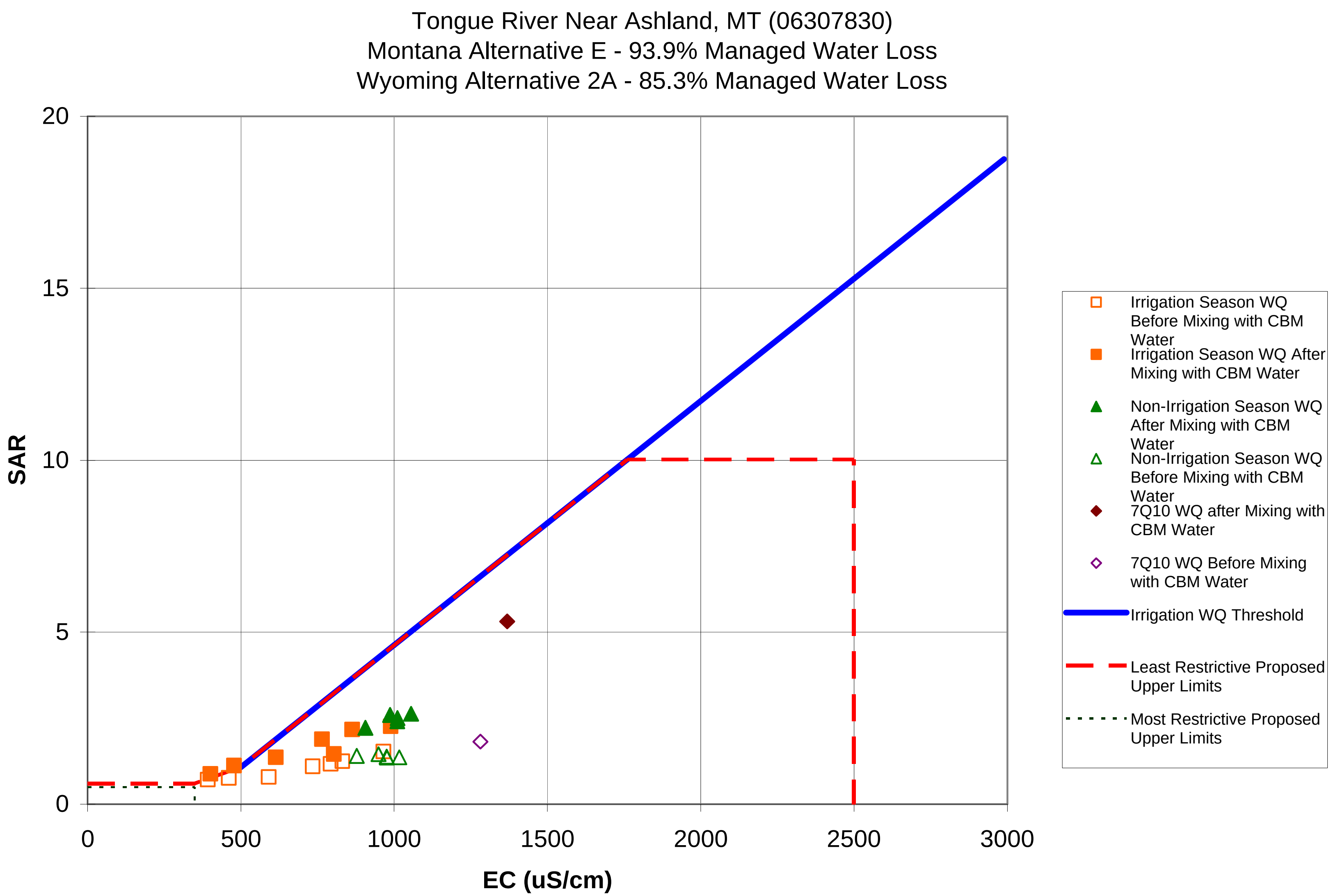
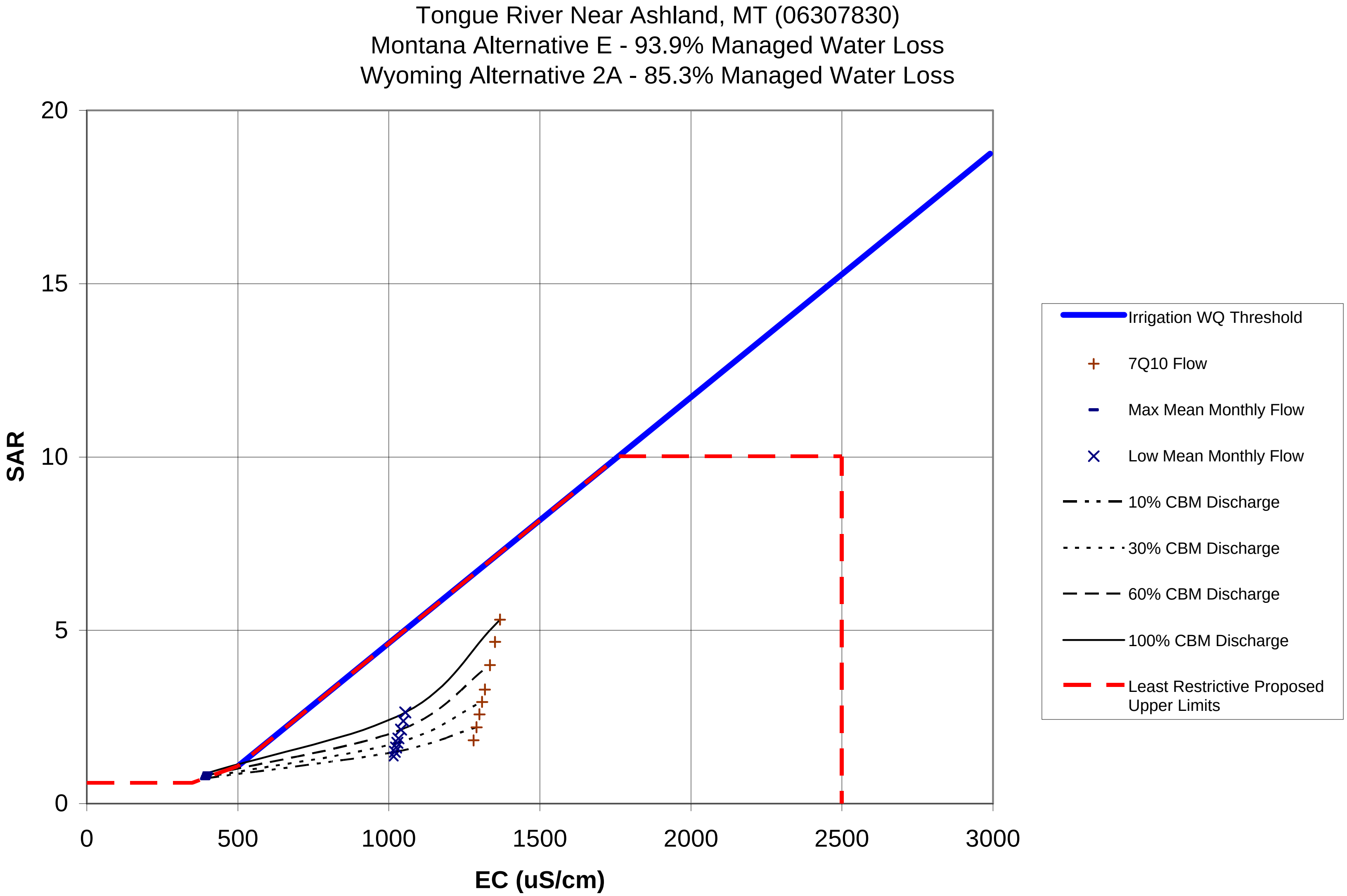


Figure 5-44 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Lower Tongue River Sub-Watershed



5.3.2 Powder River

The Powder River would receive CBM water from development in Wyoming. Since no Montana CBM wells would be allowed to discharge into the Powder River under Alternative A, all forecast alterations in water quality would be caused by CBM development in Wyoming. The analysis conducted at the station in Locate, Montana, includes the combined CBM discharges into the Powder, Little Powder, and Mizpah sub-watersheds. Table 5-12 summarizes these impacts:

Table 5-12
Surface Water Impact Analysis of the Middle/Lower Powder River Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
A	Powder River at Moorhead, MT	2.0	1000	10	3200	145	4.65	2154	224	10.7	2230	0.1	6.15	4400	79	21.8	2370
	Powder River at Locate, MT	2.0	1000	10	3200	143	4.61	2287	236	11.36	2320	1.6	6.87	3313	95	21.6	2586
C	Powder River at Moorhead, MT	2.0	1000	10	3200	145	4.65	2154	231	11.08-11.56	2226-2253	0.1	6.15	4400	86	22.0-23.2	2349-2426
	Powder River at Locate, MT	2.0	1000	10	3200	143	4.61	2287	250	11.97-13.13	2323-2361	1.6	6.87	3313	109	21.6-24.3	2384-2473
D	Powder River at Moorhead, MT	2.0	1000	10	3200	145	4.65	2154	231	11.08	2226	0.1	6.15	4400	86	20.5	2300
	Powder River at Locate, MT	2.0	1000	10	3200	143	4.61	2287	250	10.89	2268	1.6	6.87	3313	109	19.1	2259

Table 5-12
Surface Water Impact Analysis of the Middle/Lower Powder River Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
E	Powder River at Moorhead, MT	2.0	1000	10	3200	145	4.65	2154	231	11.08-11.56	2226-2253	0.1	6.15	4400	86	22.0-23.2	2349-2426
	Powder River at Locate, MT	2.0	1000	10	3200	143	4.61	2287	250	11.97-13.13	2323-2361	1.6	6.87	3313	109	21.6-24.3	2384-2473

Notes:
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.3.2.1 Alternative A

Under this alternative, the Powder River is expected to be affected only by CBM development in Wyoming, resulting in an appreciable alteration of surface water quality. Mean monthly EC and SAR values in the Powder River at the two gauging stations currently exceed the MRPL for both constituents under low mean monthly and 7Q10 flow conditions. Mean EC and SAR values currently are less than the LRPL for both constituents under similar flow conditions. After the water mixes, the resultant flow under low monthly flow conditions would increase at the two locations. The resultant EC and SAR would increase from existing stream conditions. The resultant stream water quality can be compared with the following criteria:

- MRPL: The Powder River naturally exceeds the MRPL for SAR and EC; therefore, the Powder River could not receive additional CBM discharges if the limits under consideration were adopted. The impacts forecast under Alternative A would cause the Powder River to exceed these proposed limits even more.
- LRPL: Except during 7Q10 flow conditions, the resultant water quality would be adequate to meet the LRPL for EC and SAR at both locations.
- Ayers and Westcot diagram: Except during 7Q10 flows, the resultant water quality would not cause impacts to infiltration in soils being irrigated. During the low monthly flow, essentially 100 percent of the CBM discharge could occur without causing potential effects to infiltration.

The volume and quality of surface water in the Powder River would be affected by discharges from Wyoming CBM development under Alternative A. Changes in water quality of the Powder River are expected to have minor impacts that may require downstream users to alter management practices.

5.3.2.2 Alternative C

The Powder River would receive CBM discharges from development in Wyoming and Montana and is expected to be affected by CBM development in both Wyoming and Montana under this alternative. After the water mixes, the resultant water quality would be altered by slight changes in EC; however, changes in SAR may be significant. Flow rate would also be expected to increase. The resultant water quality in streams can be compared with the following criteria:

- MRPL: The Powder River contains water that naturally exceeds the MRPL for EC and SAR; therefore, it would not be able to receive additional CBM discharge if these limits were adopted. The effects forecast from CBM water in Wyoming and Montana would further exceed these proposed limits.
- LRPL: The resultant quality of mixed water at the Moorhead station would exceed the proposed SAR limit for half the months analyzed and for the 7Q10 flow. The LRPL for EC would be exceeded only at the Moorhead station during 7Q10 flow. The resultant water quality during minimum mean monthly and 7Q10 flows would exceed the LRPL for SAR at the Locate station. During other months, the mixed water at the Locate station would be below these limits.
- Ayers and Westcot diagram: Irrigation with the mixed water at the Powder River stations would be likely to cause impacts to infiltration in soils being irrigated during 7Q10 flow. Under modeled conditions, 100 percent of the CBM discharge could occur without causing potential effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the

Ayers-Westcot diagram indicates no reduction in infiltration. The surface water quality in the Powder River would be reduced under Alternative C. These effects would likely require changes in management practices by downstream irrigators if this alternative were adopted. Although this is a legal option, so long as a CBM producer were granted a permit to degrade surface waters by the MDEQ, such as an action would be contrary to the current policy of MDEQ, and the EPA.

5.3.2.3 Alternative D

Under Alternative D, 20 percent of the produced water would be beneficially used and the remaining 80 percent would be treated to reflect the pre-development quality of surface water before discharge.

The increases in the quality of surface water shown in Table 5-12 for Alternative D would result from the discharge of untreated CBM water from CBM development in Wyoming. Changes in the volume of flow would result from treated and untreated discharges in both Montana and Wyoming. The effects that would originate from Wyoming would be the same as were detailed above under Alternative A. Effects on surface water from CBM development in Montana would result from increases in base flow.

5.3.2.4 Preferred Alternative E

The Powder River is expected to be affected by CBM development in both Wyoming and Montana, resulting in an appreciable alteration of surface water quality. Under Preferred Alternative E, volume of flows and SAR and EC values are forecast to increase. The resultant water quality in streams can be compared with the following criteria:

- MRPL: Figures 5-45 and 5-46 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Lower Powder River sub-watershed, as modeled at the USGS gauging station at Locate, Montana. The Powder River naturally exceeds the MRPL for EC and SAR; therefore, it could not receive any CBM discharge if these limits were adopted. The Powder River would exceed these proposed limits even further as a result of the impacts forecast under this alternative.
- LRPL: The LRPL for both EC and SAR would be exceeded during an average of five months of each year as well as during 7Q10 flows.
- Ayers and Westcot diagram: Figure 5-47 illustrates the suitability for irrigation of the Lower Powder River at Locate before and after the river mixes with Discharges of CBM produced water.A comparison of the resultant quality of mixed water with the Ayers-Westcot diagram in Figure 5-47 indicates that the mixed water would not cause impacts on infiltration to irrigated soils under modeled conditions except during 7Q10 flow. Figure 5-48 illustrates the relationship between EC and SAR in the Lower Powder River at Locate after the river mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially 100 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Of course site-specific conditions and the actual surface water standards adopted by the MBER will be the most important factors in determining the actual water management practices within the Montana portion of the PRB. The MDEQ cannot allow discharges of CBM water to impact surface water conditions in excess of prevailing regulations and standards. CBM producers in the Wyoming portion of this watershed will be held to the same standards if the Montana standards are approved by the EPA and given CWA standing.

Figure 5-45 Stream EC Before and After Mixing-Lower Powder River Sub-Watershed

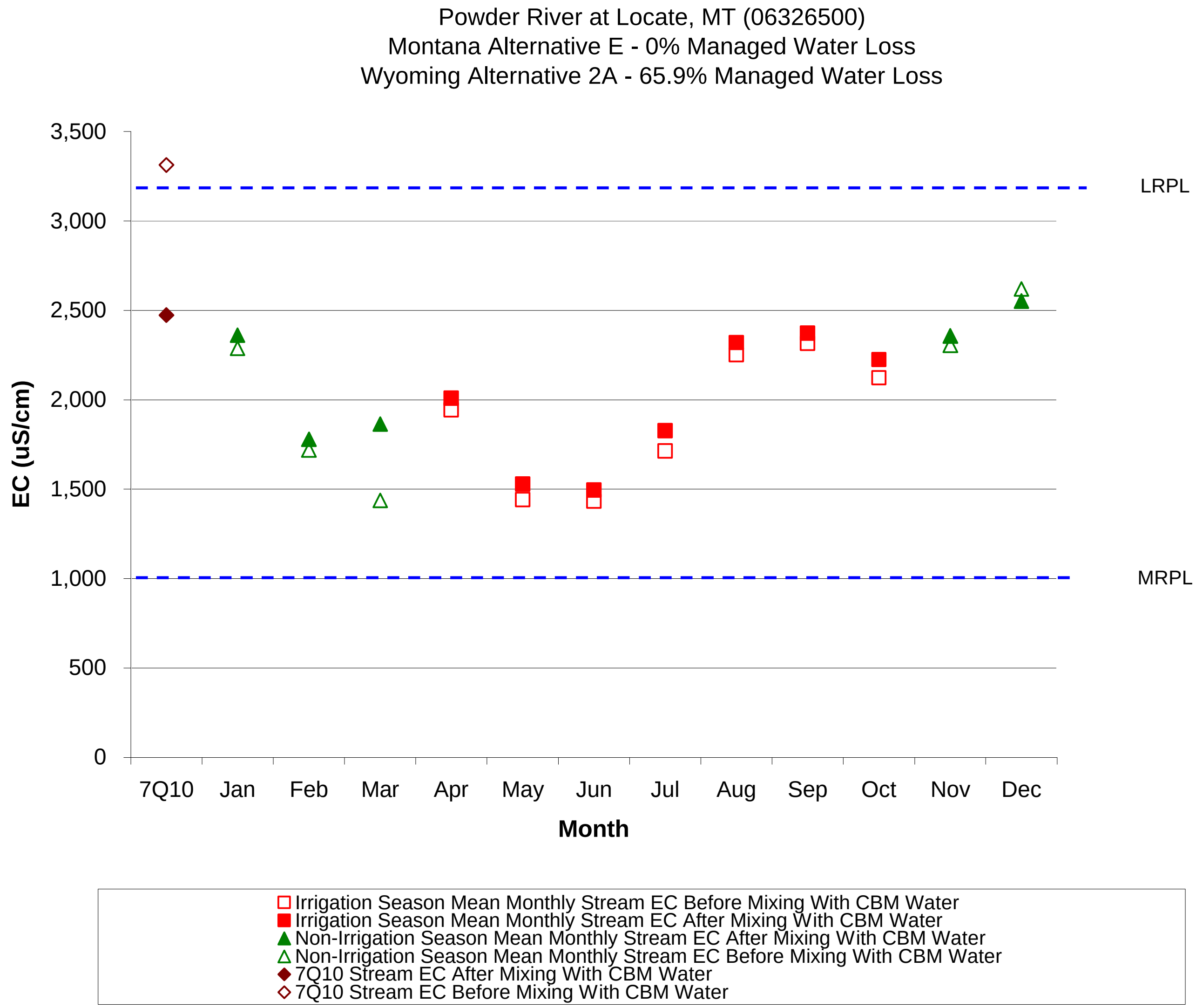


Figure 5-46 Stream SAR Before and After Mixing-Lower Powder River Sub-Watershed

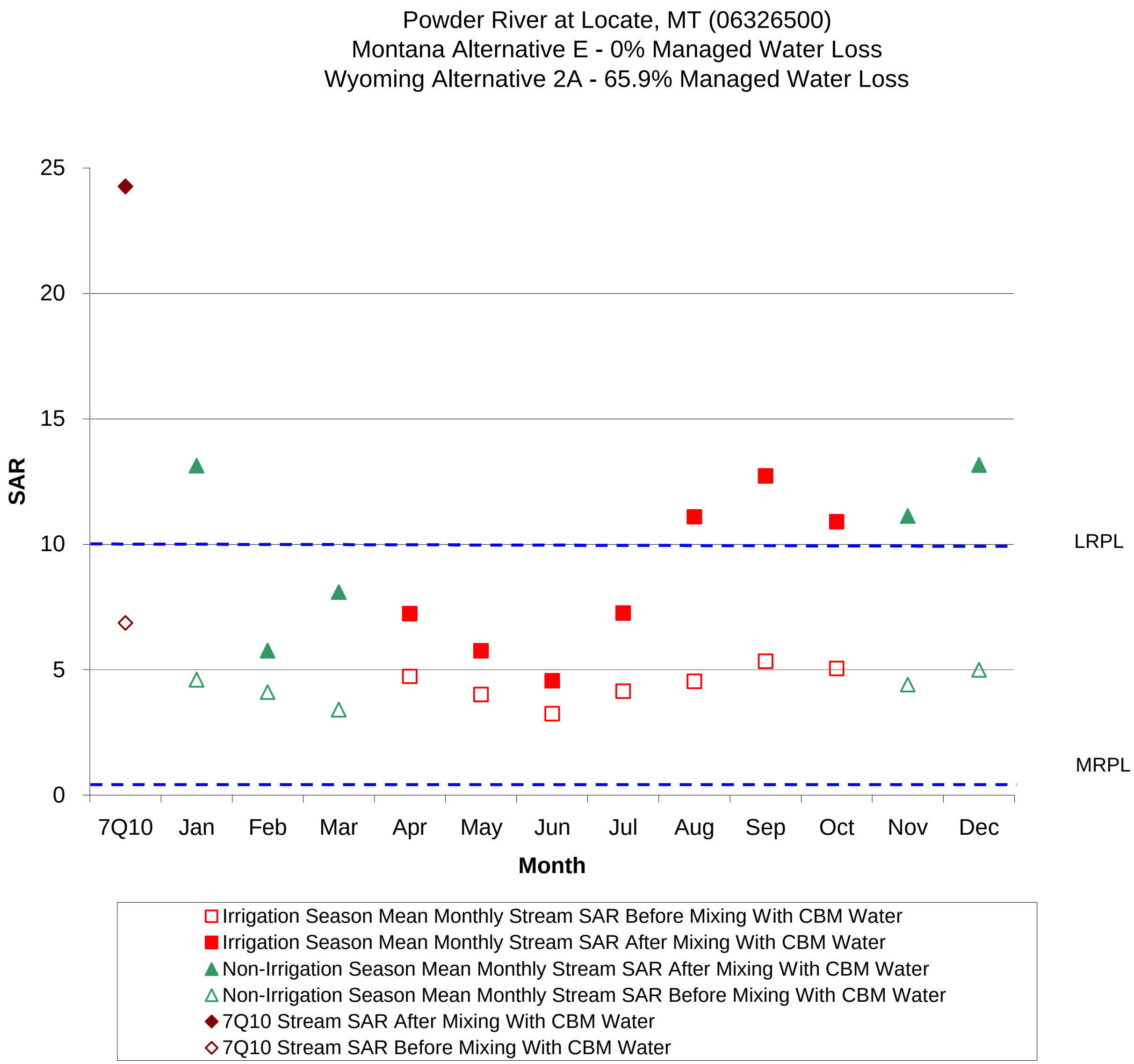


Figure 5-47 Irrigation Suitability Before and After Mixing – Lower Powder River Sub-Watershed

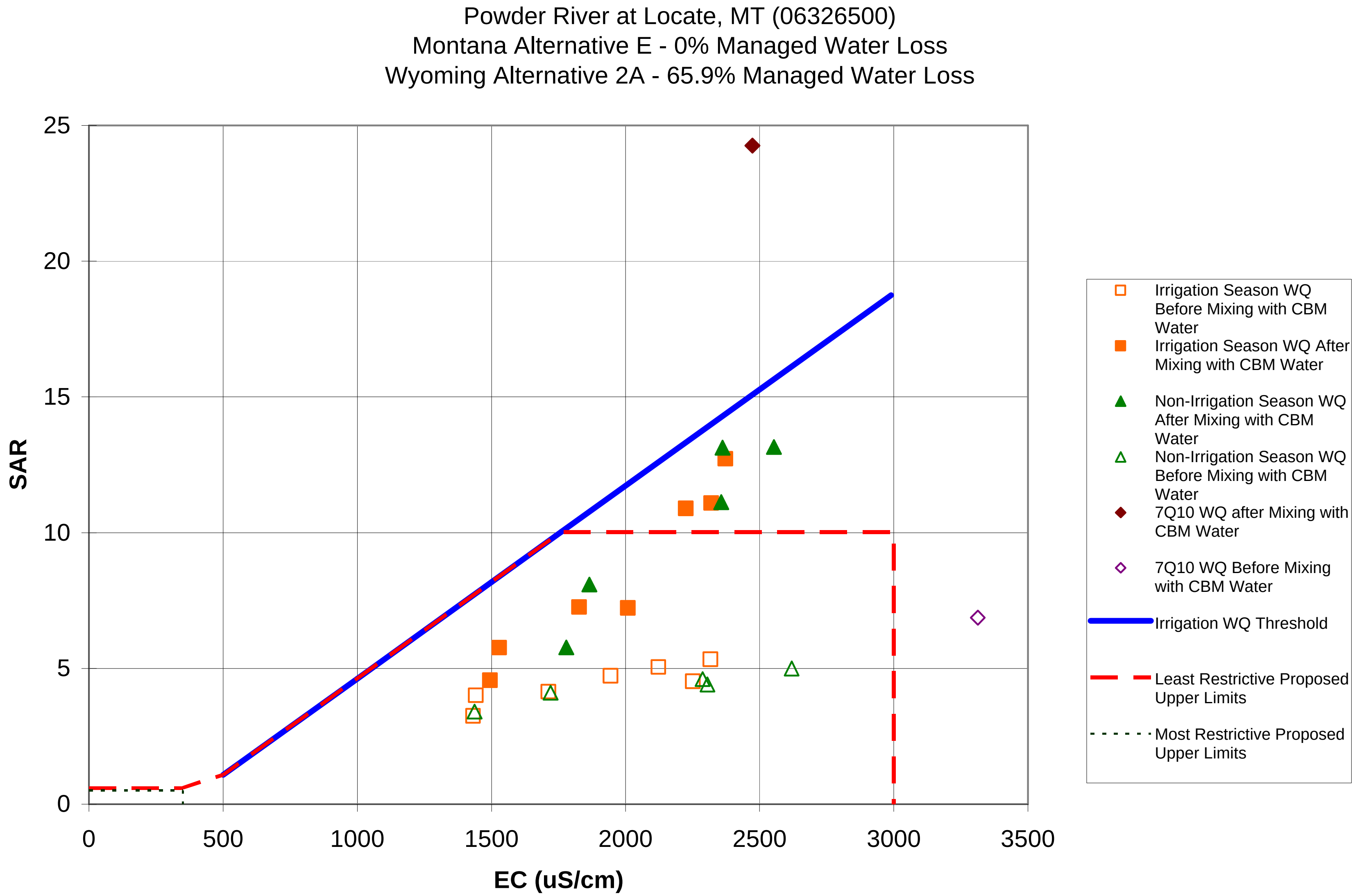
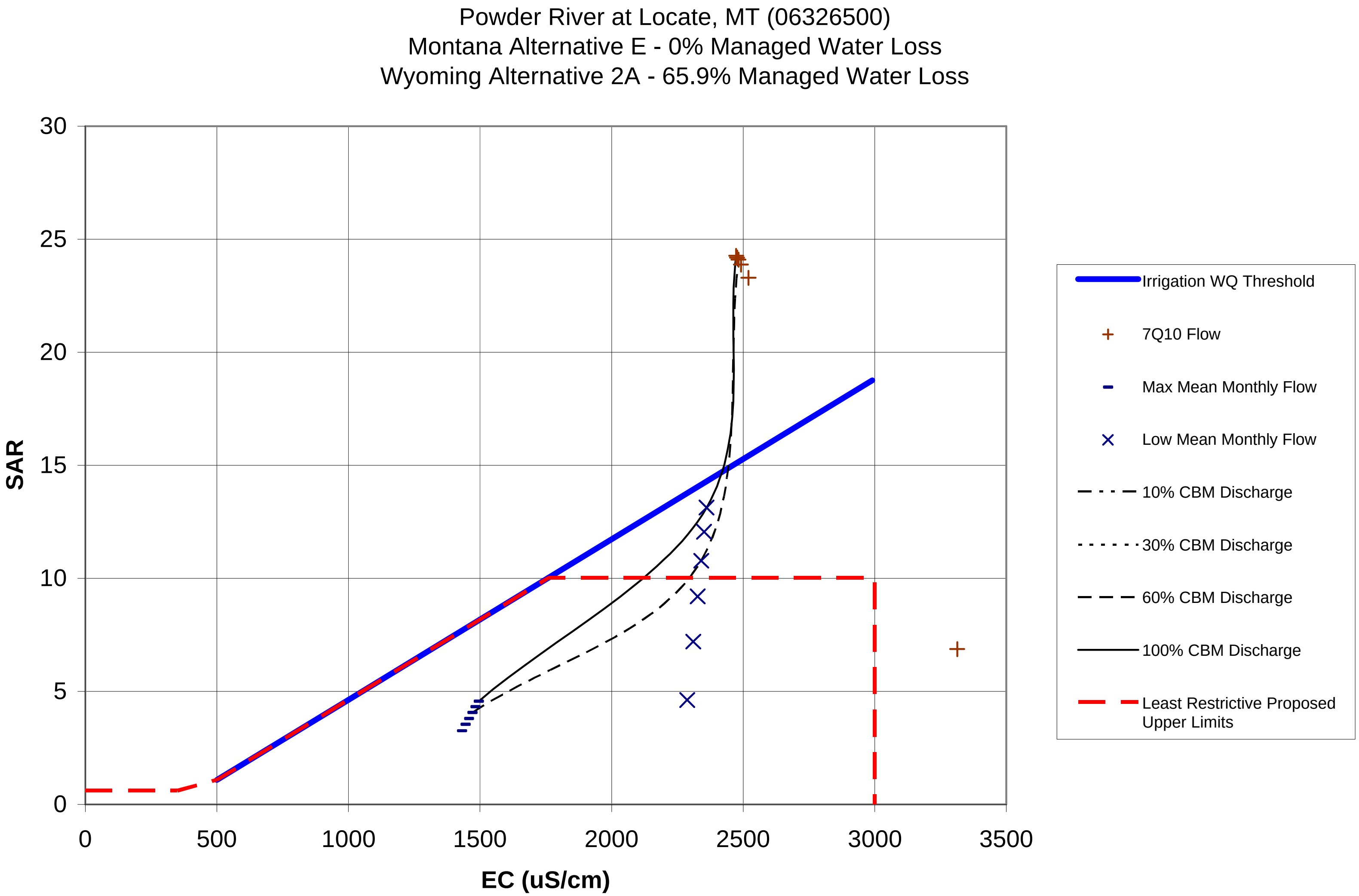


Figure 5-48 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Lower Powder River Sub-Watershed



The Powder River contains variable amounts of water that naturally exceeds the MRPL for EC and SAR. The resultant quality of mixed water during the irrigation and non-irrigation seasons would generally be below the LRPL for both constituents, as well as below the Ayers-Westcot threshold. Therefore, Preferred Alternative E would allow for the possibility of 100 percent discharge of CBM water into the Powder River sub-watershed, and effects to surface water would be the same as were described for Alternative C. However, local conditions would dictate the actual discharge permits for individual CBM projects. No changes in management practices are foreseen by downstream irrigators.

5.3.3 Little Powder River

The Little Powder River has its headwaters in the Wyoming portion of the PRB and as such, it is expected to receive CBM water from development in Wyoming. The analysis for this stream is conducted at the station in Weston, Wyoming, near the state line. No effects would result from CBM development in Montana under any alternative at this station. The impacts from wells in Montana downstream of this station are discussed in the analysis for the Powder River at Locate station.

5.3.4 Mizpah Creek

Mizpah Creek carries water into the Powder River in Montana. No CBM wells in Wyoming could affect this sub-watershed. Instead, effects to Mizpah Creek would result from the discharge of CBM produced water in Montana only. Table 5-13 summarizes changes predicted in water quality in Mizpah Creek just upstream from its junction with the Powder River.

Table 5-13
Surface Water Impact Analysis of the Mizpah Creek Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (μS/cm)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)
A	Mizpah Creek at Mizpah, MT	2.0	1000	10	3200	0.26	16.6	3503	0.26	16.6	3503	0.0	--	--	--	--	--
C	Mizpah Creek at Mizpah, MT	2.0	1000	10	3200	0.26	16.6	3503	1.26	20.43-35.26	2663-3163	0.0	--	--	1.0	11.1-22.6	1271-2451
D	Mizpah Creek at Mizpah, MT	2.0	1000	10	3200	0.26	16.6	3503	1.26	16.6	3503	0.0	--	--	1.0	8.17	1131
E	Mizpah Creek at Mizpah, MT	2.0	1000	10	3200	0.26	16.6	3503	1.0	20.43-35.26	2663-3163	0.0	--	--	1.0	11.1-22.6	1271-2451

Notes:
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
μS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.3.3.1 Alternative A

Mizpah Creek contains low-quality water that has limited use for irrigation but can be used for stock watering and by wildlife. This sub-watershed is not expected to experience effects from CBM development under Alternative A. The water quality in streams can be compared with the following criteria:

- MRPL: Mean monthly EC and SAR values in Mizpah Creek currently exceed the MRPL for both constituents under low mean monthly and 7Q10 flow conditions.
- LRPL: Except for 2 months out of the year, the existing water quality in Mizpah Creek would exceed the LRPL for SAR but would be adequate to meet the LRPL for EC for 11 months of the year.
- Ayers and Westcot diagram: Except for 3 months out of the year, the existing water quality would reduce infiltration to irrigated soils.

5.3.3.2 Alternative C

Mizpah Creek contains water that naturally exceeds the LRPL for EC and SAR. CBM discharges would decrease the EC from existing conditions and would increase the SAR. The resultant water quality in streams can be compared with the following criteria:

- MRPL: The water quality in Mizpah Creek naturally exceeds the MRPL for EC and SAR; therefore, it would not be able to receive additional CBM discharges if these limits are adopted. The impacts forecast under Alternative C would further exceeds these proposed limits.
- LRPL: The water quality in Mizpah Creek exceeds the LRPL for EC and SAR; therefore, it would not be able to receive additional CBM discharges if these limits were adopted.
- Ayers and Westcot diagram: The quality of mixed water at the Mizpah station would likely cause impacts to infiltration in irrigated soils during all flows, except for 1 or 2 high-flow months per year.

The surface water quality of Mizpah Creek would be reduced under Alternative C, requiring changes in management practices of downstream users. Although this is a legal option, so long as a CBM producer were granted a permit to degrade surface waters by the MDEQ, such as an action would be contrary to the current policy of MDEQ, and the EPA.

5.3.3.3 Alternative D

Under Alternative D, 20 percent of the produced water would be beneficially used and the remaining 80 percent would be treated to reflect the pre-development quality of before discharge.

The increases in surface water quality shown in Table 5-13 for Alternative D are a result of the discharge of untreated CBM water from CBM development in Wyoming. Changes in the volume of flow are caused by treated and untreated discharges in both Montana and Wyoming. The effects that originate from Wyoming would be the same as those were described under Alternative A. Effects on surface water conditions from CBM development in Montana are a result of the increases in base flow.

5.3.3.4 Preferred Alternative E

In Montana, 125 CBM wells are projected to be productive in this sub-watershed, but no CBM wells in Wyoming will produce. Under Preferred Alternative E, impacts to water quality are expected to be the same as under Alternative C, since all CBM produced water could be discharged under this alternative. The resultant water quality in streams can be compared with the following criteria:

- MRPL: Figures 5-49 and 5-50 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Mizpah Creek sub-watershed, as modeled at the USGS gauging station near Mizpah, Montana. The water quality in Mizpah Creek naturally exceeds the MRPL for EC and SAR; therefore, it would not be able to receive additional CBM discharges if these limits were adopted. The impacts forecast under Alternative C further exceed these proposed limits.
- LRPL: The water quality in Mizpah Creek exceeds the LRPL for EC and SAR; therefore, it would not be able to receive additional CBM discharges if these limits were adopted.
- Ayers and Westcot diagram: Figure 5-51 illustrates the suitability for irrigation of Mizpah Creek at Mizpah before and after the creek mixes with discharges of CBM produced water.A comparison of the resultant quality of mixed water with the Ayers-Westcot diagram under modeled conditions in Figure 5-51 indicates that the quality of the mixed water at the Mizpah station would likely cause impacts to infiltration in irrigated soils during all flows except for 1 or 2 high-flow months a year. Figure 5-52 illustrates the relationship between EC and SAR in Mizpah Creek after the creek mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, about 10 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-49 Stream EC Before and After Mixing- Mizpah Creek Sub-Watershed

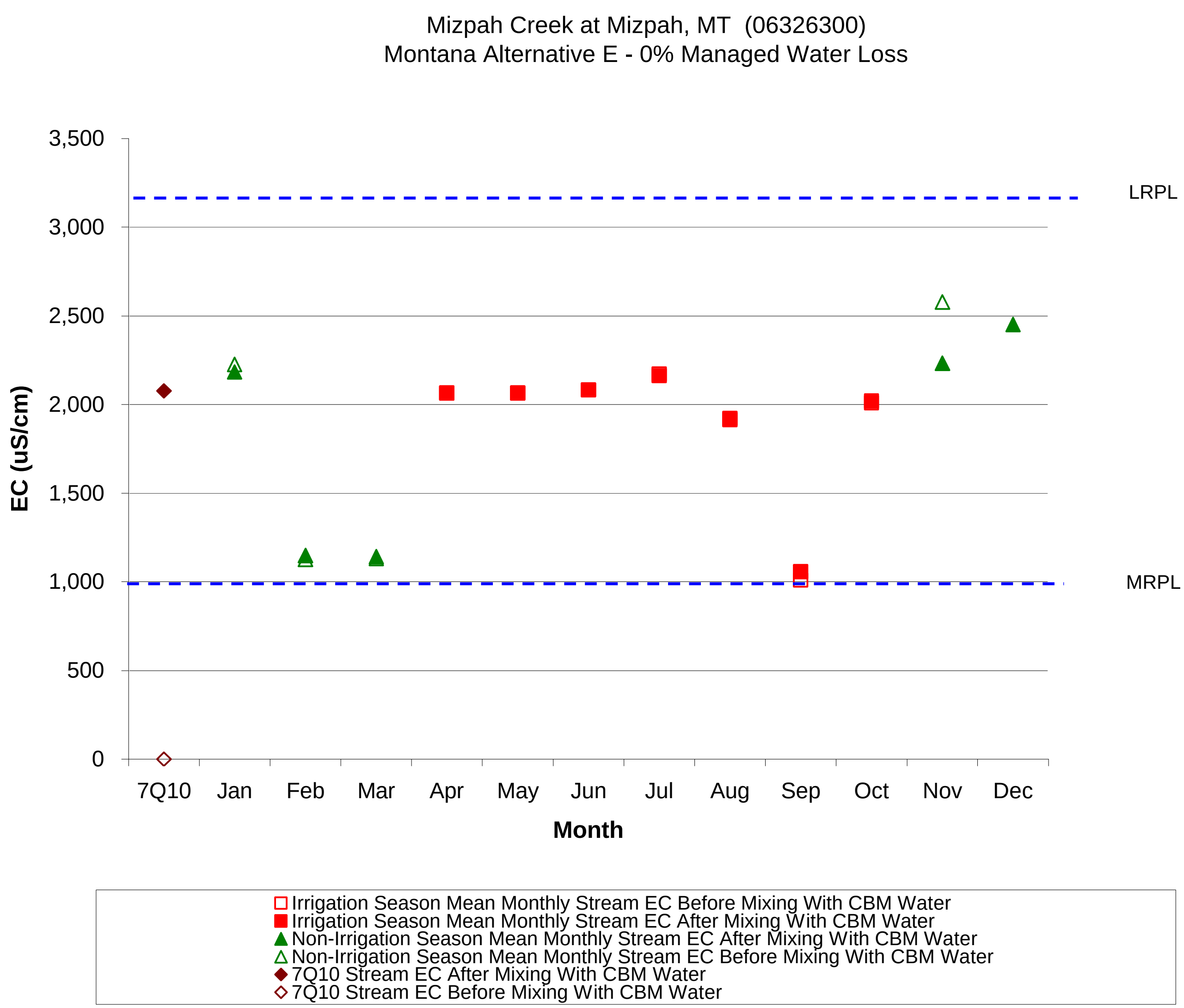


Figure 5-50 Stream SAR Before and After Mixing- Mizpah Creek Sub-Watershed

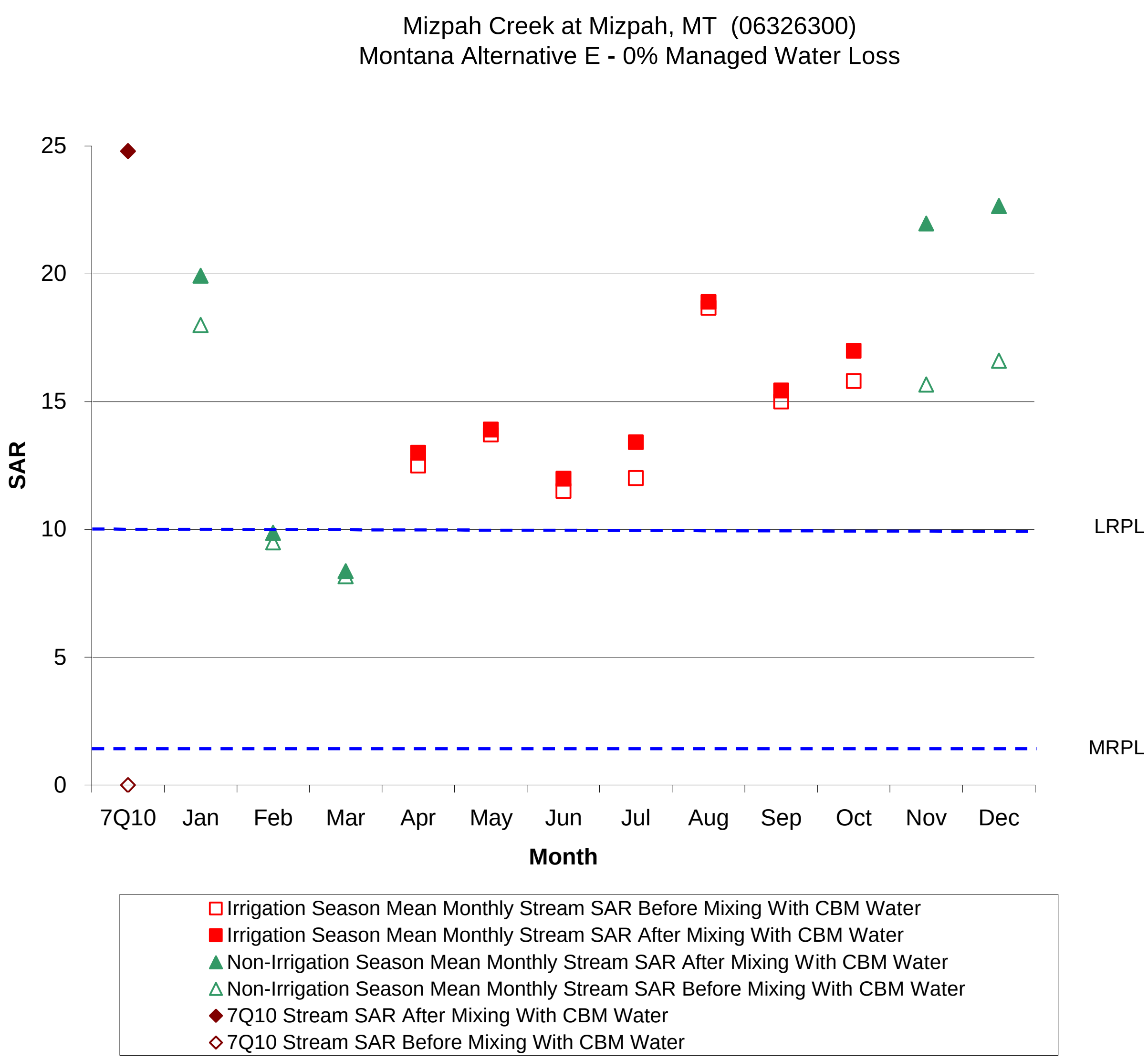


Figure 5-51 Irrigation Suitability Before and After Mixing – Mizpah Creek Sub-Watershed

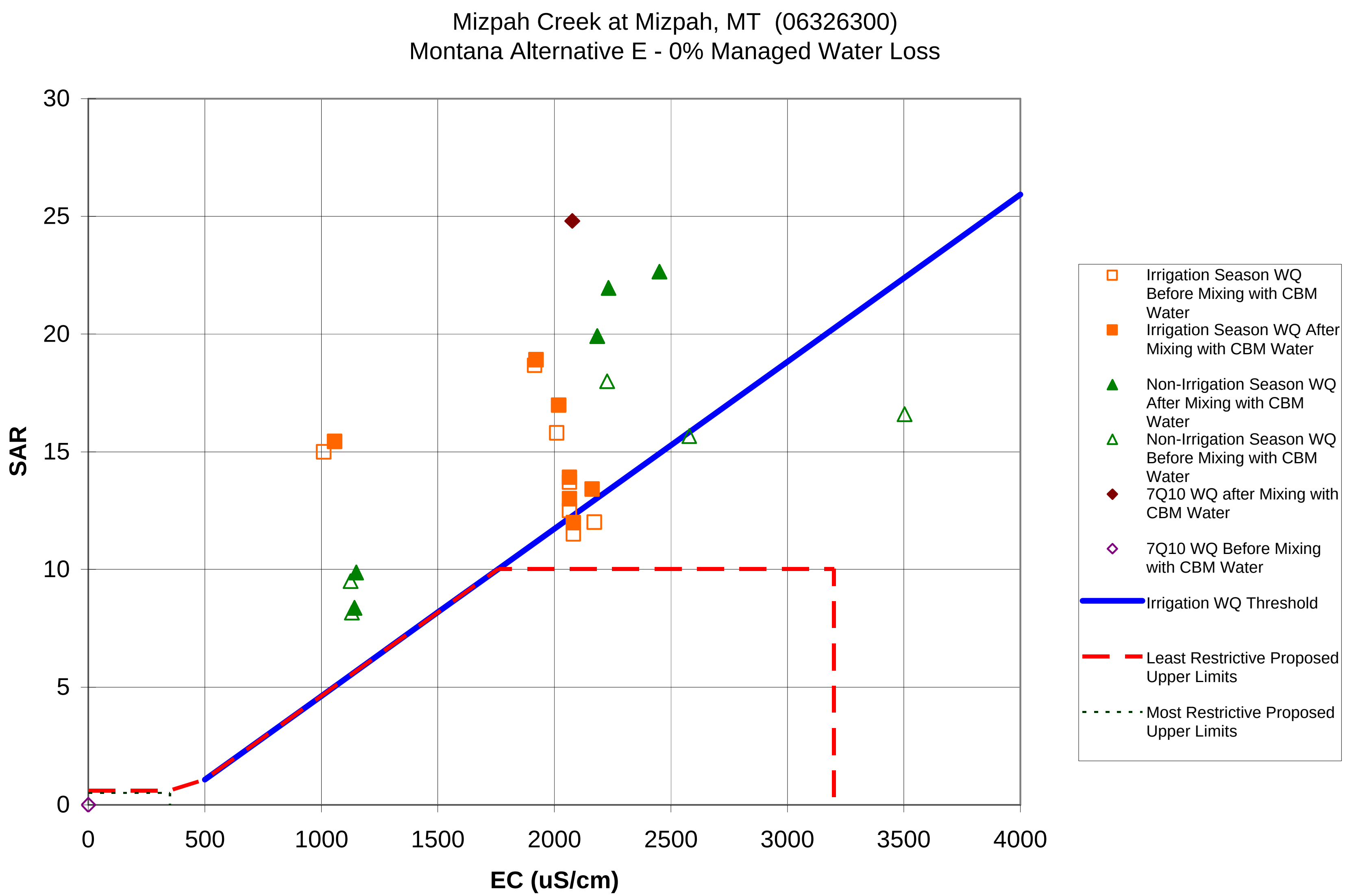
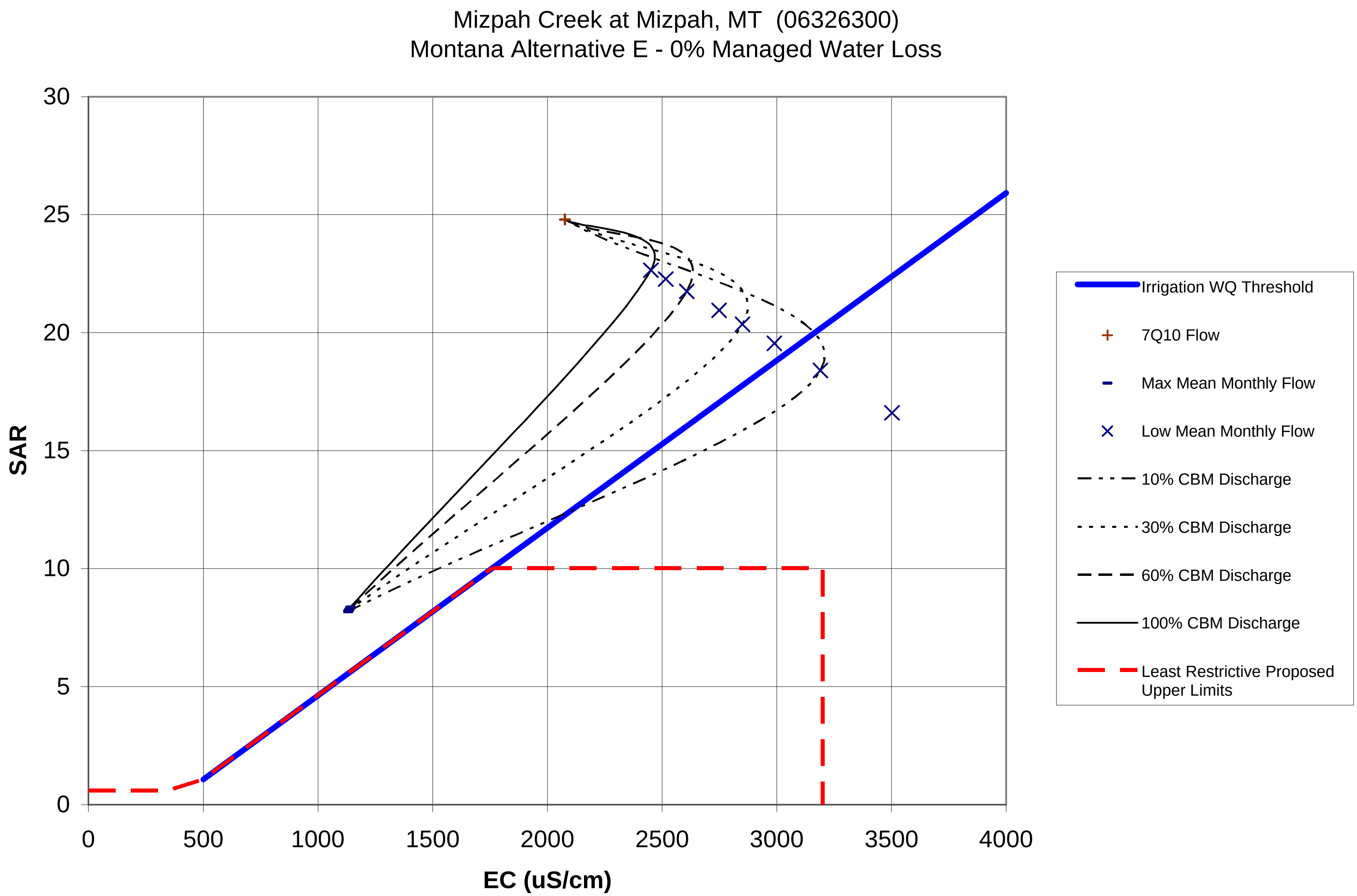


Figure 5-52 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Mizpah Creek Sub-Watershed



Both the existing and the resultant quality of mixed water in the Mizpah Creek sub-watershed exceed the proposed limits for EC and SAR for some portion of the year. Nonetheless, beneficial uses for the existing low volumes of low-quality water from Mizpah Creek would not be reduced. Therefore, the Preferred Alternative E allows 100 percent of the produced water to be discharged.

5.3.4 Bighorn/Little Bighorn Rivers

These rivers carry water from the Bighorn Mountains north from Wyoming into Montana. No CBM wells in Wyoming are expected to affect these rivers. Table 5-14 below summarizes the effects to water quality for two stations along the Little Bighorn River and one on the Bighorn River, just upstream from its confluence with the Yellowstone River.

Table 5-14
Surface Water Impact Analysis of the Little Bighorn/Bighorn River Sub-Watersheds

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
A	Little Bighorn River at state line, near Wyola, MT	0.5	500	10	2500	110	0.53	548	110	0.53	548	47	0.8	629	47	0.8	629
	Little Bighorn River near Hardin, MT	0.5	500	10	2500	123	0.99	768	123	0.99	768	21	1.6	830	21	1.6	830
	Lower Bighorn River at Bighorn, MT	0.5	500	10	2500	1523	2.08	952	1523	2.08	952	870	2.8	989	870	2.8	989

Table 5-14
Surface Water Impact Analysis of the Little Bighorn/Bighorn River Sub-Watersheds

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
C	Little Bighorn River at state line, near Wyola, MT	0.5	500	10	2500	110	0.53	549	115	2.26-2.64	623-632	47	0.8	629	52	4.59-5.42	787-807
	Little Bighorn River near Hardin, MT	0.5	500	10	2500	123	0.99	768	133	3.94-4.59	881-896	21	1.6	830	31	13.9-16.7	1287-1353
	Lower Bighorn River at Bighorn, MT	0.5	500	10	2500	1523	2.08	952	1542	2.54-2.64	968-970	870	2.8	989	889	3.58-3.76	1015-1020

Table 5-14
Surface Water Impact Analysis of the Little Bighorn/Bighorn River Sub-Watersheds

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
D	Little Bighorn River at state line, near Wyola, MT	0.5	500	10	2500	110	0.53	548	115	0.53	548	47	0.8	629	52	0.8	605
	Little Bighorn River near Hardin, MT	0.5	500	10	2500	123	0.99	768	133	0.99	768	21	1.6	830	31	1.53	784
	Lower Bighorn River at Bighorn, MT	0.5	500	10	2500	1523	2.08	952	1542	2.08	952	870	2.8	989	889	2.78	986

Table 5-14
Surface Water Impact Analysis of the Little Bighorn/Bighorn River Sub-Watersheds

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
E	Little Bighorn River at state line, near Wyola, MT	0.5	500	10	2500	110	0.53	548	115	2.64-3.26	623-632	47	0.8	629	52	4.59-5.42	787-807
	Little Bighorn River near Hardin, MT	0.5	500	10	2500	123	0.99	768	133	3.94-4.59	881-896	21	1.6	830	31	13.9-16.7	1287-1353
	Lower Bighorn River at Bighorn, MT	0.5	500	10	2500	1523	2.08	962	1542	2.54-2.64	968-970	870	2.8	989	889	3.58-3.76	1015-1020

Notes:
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.3.4.1 Alternative A

No CBM wells in Wyoming or Montana are expected to affect these rivers under Alternative A. Water quality and volume of flow in streams are expected to remain unchanged. The existing water quality in streams can be compared with the following criteria:

- MRPL: Existing water monthly averages in streams at Wyola except during 2 months of the year exceed the MRPL for SAR; likewise, the existing stream water exceeds the MRPL for EC for all but 3 months of the year. Water quality at the other two stations exceeds these limits throughout the year. The streams could not receive CBM discharges unless the produced water was of better quality than the streams.
- LRPL: The existing water monthly averages for the streams do not exceed the LRPL for both constituents during the year at any of the three stations.
- Ayers and Westcot diagram: Irrigation with the existing stream water at the three stations would not likely reduce infiltration to irrigated soils.

All current uses of these waters would be maintained under Alternative A.

5.3.4.2 Alternative C

Under Alternative C, the effects to the Little Bighorn and Lower Bighorn Rivers would result from CBM discharges in Montana only. The resultant impacts to water quality for these rivers would include increases in EC and SAR. Flows would increase slightly. The resultant water quality in streams can be compared with the following criteria:

- MRPL: The water quality in these streams naturally exceeds the MRPL for EC and SAR during several months; therefore, these streams could not receive additional CBM discharges if these limits were adopted. The effects forecast from CBM development would further exceed these proposed limits.
- LRPL: The water quality at the Hardin station only during 7Q10 flow conditions is above the LRPL for SAR. The resultant water quality would be adequate to meet these limits for the remaining stations.
- Ayers and Westcot diagram: Irrigation with the mixed water at the Wyola and Hardin stations would be likely to cause impacts to infiltration in irrigated soils during several months of the year. The resultant water quality represents a low EC-to-SAR relationship; thus, the water would likely alter clayey soils if it is used for irrigation. Water quality at the station near Bighorn would likely cause no impacts to infiltration and would be adequate for use for irrigation. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

The water quality in the Bighorn Rivers in Montana will be slightly reduced under Alternative C, resulting in minor changes to management practices by downstream users for continued use in irrigation. Although this is a legal option, so long as a CBM producer were granted a permit to degrade surface waters by the MDEQ, such as an action would be contrary to the current policy of MDEQ, and the EPA. The flows in these rivers are of sufficient quality and quantity to dilute any CBM discharges without affected irrigation use with the mixed stream water.

5.3.4.3 Alternative D

Under Alternative D, 20 percent of produced water would be used for beneficial uses and the remaining 80 percent would be treated to the quality of pre-development water before discharge.

The increases in the quality of surface water shown in Table 5-14 for Alternative D would result from the discharge of untreated CBM water from CBM development in Wyoming. Changes in the volume of flow are a result of treated and untreated discharges in both Montana and Wyoming. The effects that originate from Wyoming would be the same as were described under Alternative A. Effects on surface water from CBM development in Montana are a result of the increases in base flow.

5.3.4.4 Preferred Alternative E

The Bighorn River and its tributary the Little Bighorn River would not likely be affected by CBM development in Wyoming but would likely be affected by CBM wells on Indian Lands and state and fee lands in Montana.

Under Preferred Alternative E, potential impacts to water quality in the Bighorn and Little Bighorn Rivers would be the same as were described under Alternative C. Preferred Alternative E would allow for discharge of 100 percent of the CBM water. Actual discharge from future CBM projects would depend on site-specific conditions and approval of a water management plan. The WMP would need to show minimal impacts to beneficial use to be approved. In Table 5-14, discharges located within the upper segments of the sub-watershed (upstream of the Wyola and Hardin stations) would cause major impacts and would likely be restricted in number and volume. The impact of discharges near the downstream segments of the sub-watershed would be less, however, and could be approved in larger numbers. Cumulative discharges of the entire volume of CBM water would be minor at the downstream end and would not require changes in management by end users. The resultant water quality in streams near Hardin, Montana, can be compared with the following criteria:

- MRPL: Figures 5-53 and 5-54 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Little Bighorn River sub-watershed, as modeled at the USGS gauging station near Hardin, Montana. The water quality in this stream naturally exceeds the MRPL for EC and SAR during several months; therefore, the stream would not be able to receive additional CBM discharges if these limits were adopted. The effects forecast from CBM development would further exceed these proposed limits.
- LRPL: The water quality at the Hardin station is expected to be adequate to meet the LRPL for EC 2[nd] SAR during all months, but at the 7Q10 flow, the LRPL for SAR would be exceeded.
- Ayers-Westcot diagram: Figure 5-55 illustrates the suitability for irrigation of the Little Bighorn River near Hardin before and after the river mixes with discharges of CBM produced water.A comparison of the resultant mixed water quality under modeled conditions with the Ayers-Westcot diagram in Figure 5-55 indicates that there would be some reduction in infiltration during some months of the irrigation season and under 7Q10 flow conditions. The resultant water quality represents a low EC–to-SAR relationship; thus, the water would likely impact clayey soils if it is used for irrigation. Figure 5-56 illustrates the relationship between EC and SAR in the Little Bighorn River near Hardin after the river mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, about 60

percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-53 Stream EC Before and After Mixing-Little Bighorn River Sub-Watershed

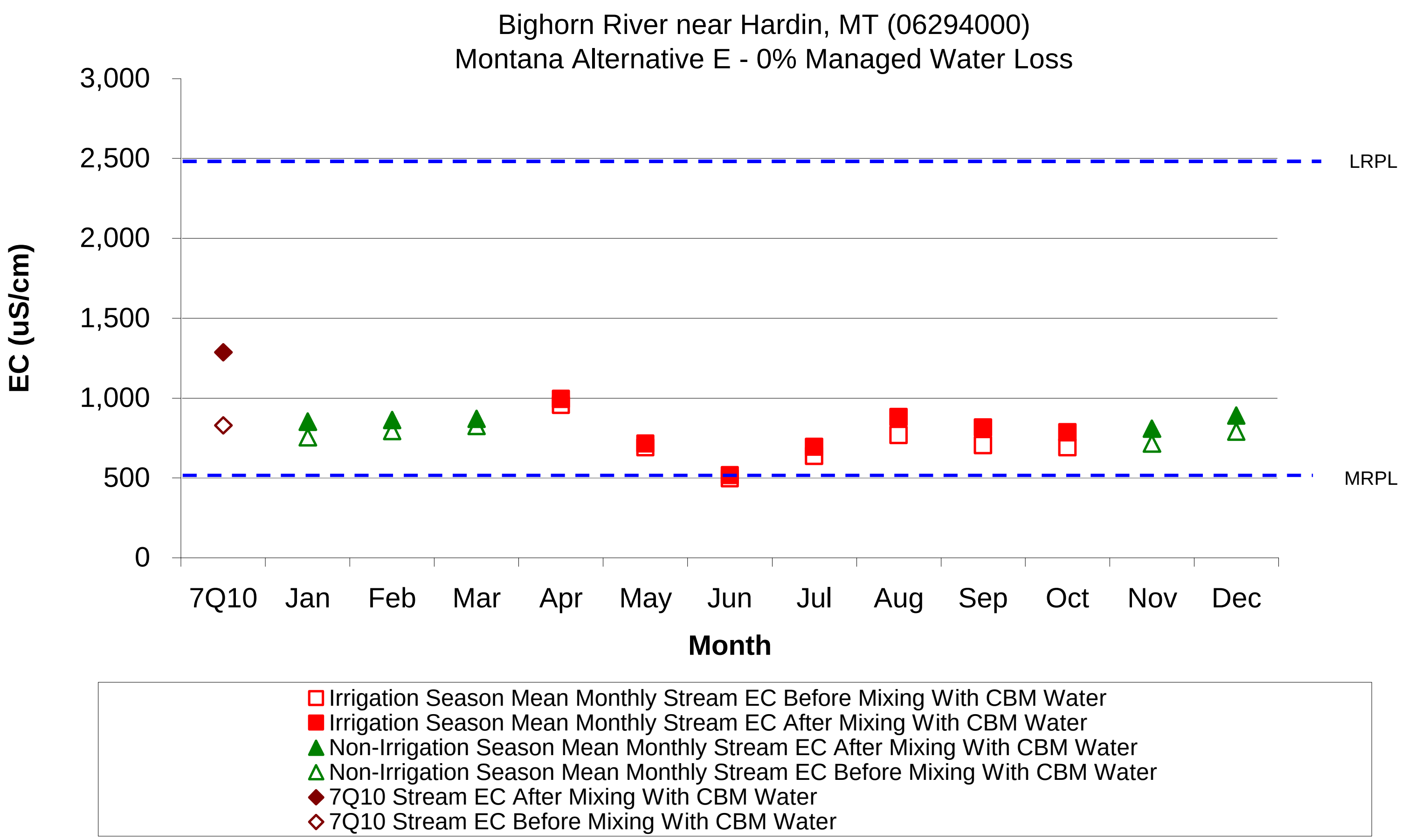


Figure 5-54 Stream SAR Before and After Mixing- Little Bighorn River Sub-Watershed

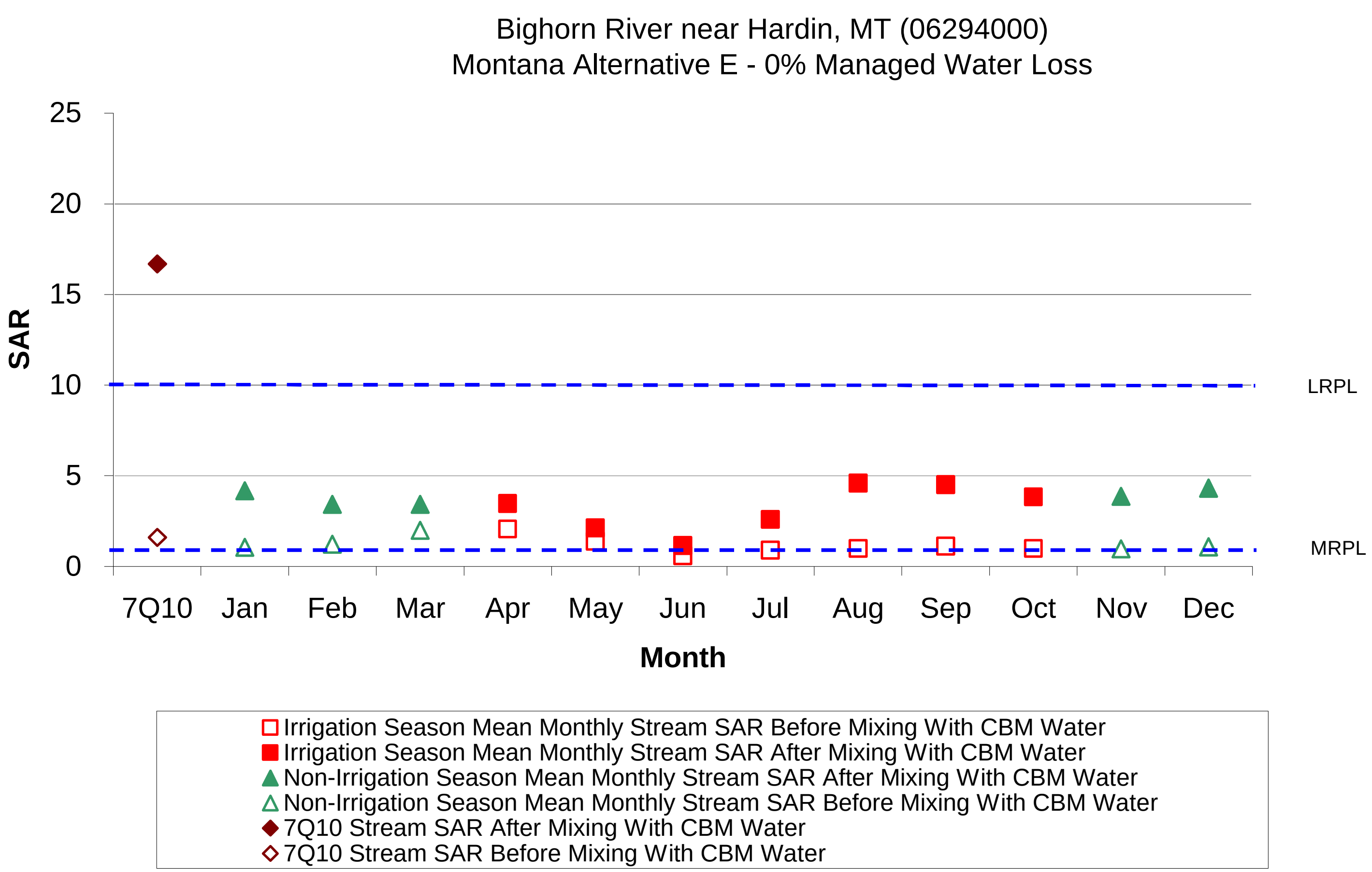


Figure 5-55 Irrigation Suitability Before and After Mixing – Little Bighorn River Sub-Watershed

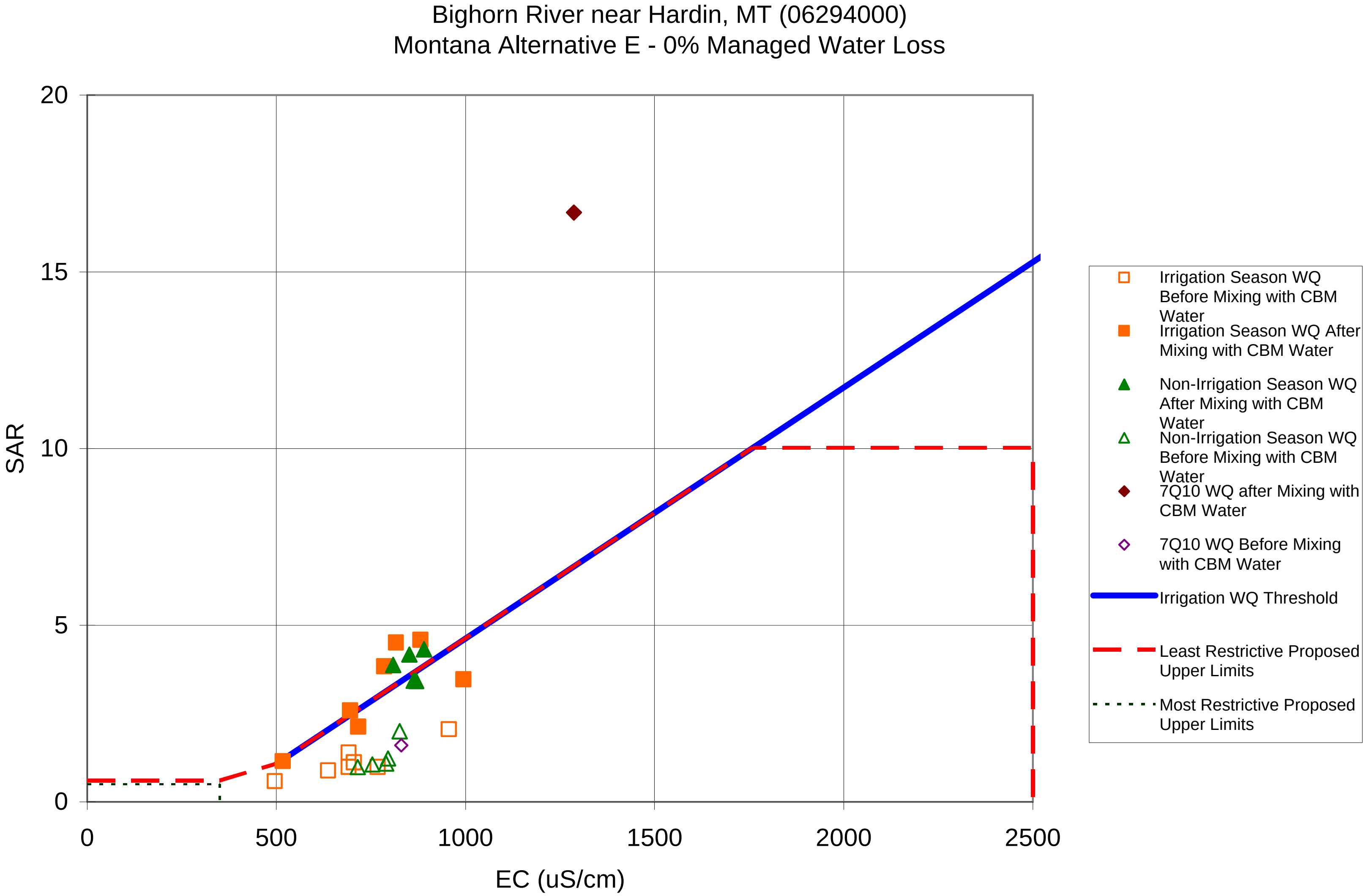
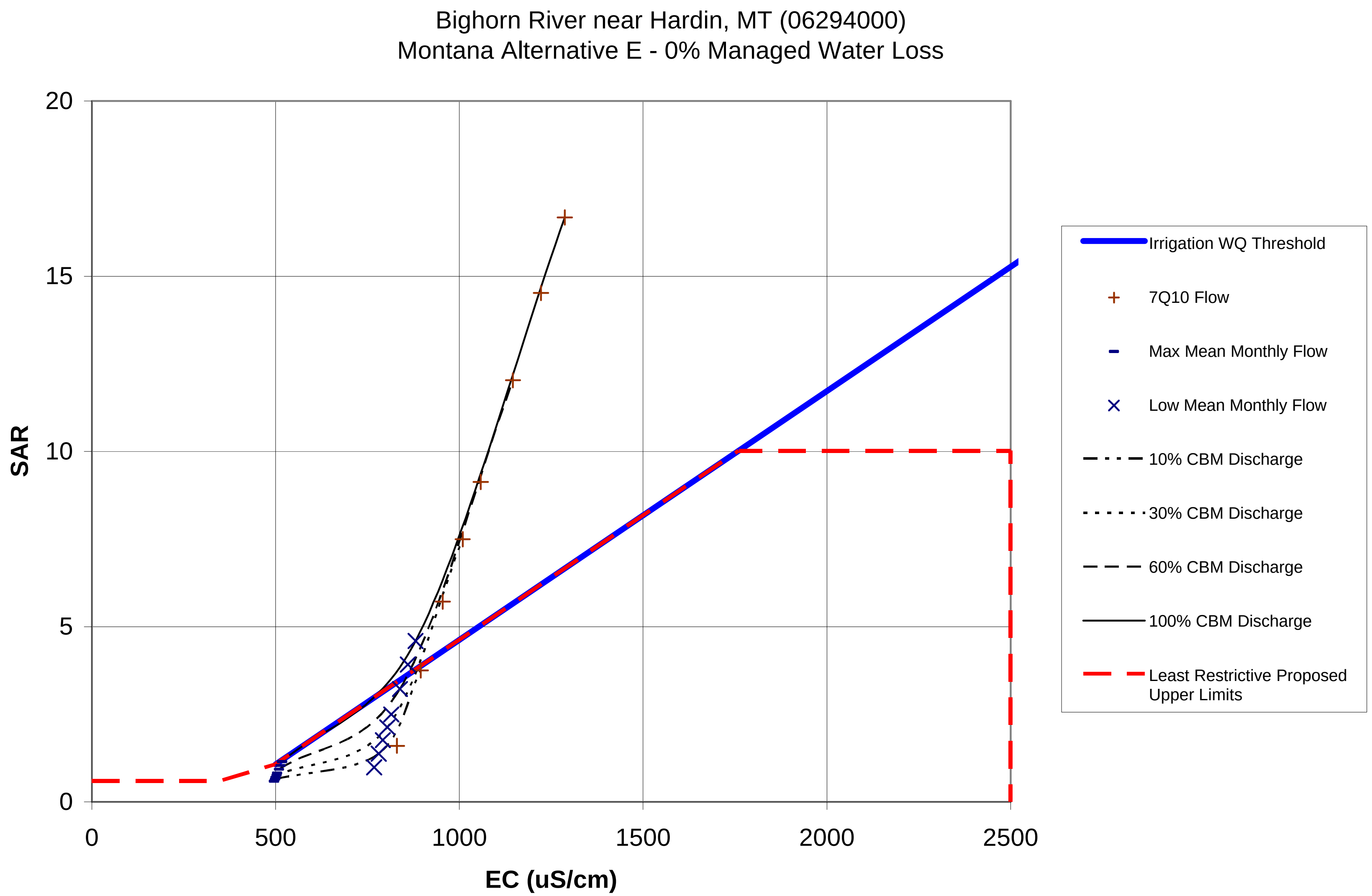


Figure 5-56 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Little Bighorn River Sub-Watershed



Under Alternative E, the resultant water quality in streams near Bighorn, Montana, can be compared with the following criteria:

- MRPL: Figures 5-57 and 5-58 are used to illustrate at which months during the year the existing water quality and resultant mixed water quality during mean monthly flow and 7Q10 flow conditions would exceed the MRPL and LRPL being considered for water quality in the Lower Bighorn River sub-watershed, as modeled at the USGS gauging station near Bighorn, Montana. The water quality in this stream is naturally above the MRPL for EC and SAR during several months, and therefore, the stream would not be able to receive additional CBM discharges if these limits were adopted. The forecast effects from CBM development would further be in excess of these proposed limits.
- LRPL: The LRPL for EC and SAR would not be exceeded during either the minimum mean monthly flow or during 7Q10 flow conditions.
- Ayers-Westcot diagram: Figure 5-59 illustrates the suitability for irrigation of the Lower Bighorn River near Bighorn before and after mixing with Discharges of CBM produced water. Under modeled conditions, a comparison of the resultant mixed water quality with the Ayers-Westcot diagram in Figure 5-59 indicates that there would be no infiltration impacts and the mixed water would be adequate for use for irrigation. Figure 5-60 illustrates the relationship between EC and SAR in the Lower Bighorn River near Bighorn after mixing with varying proportions of Discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially 100 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-57 Stream EC Before and After Mixing-Lower Bighorn River Sub-Watershed

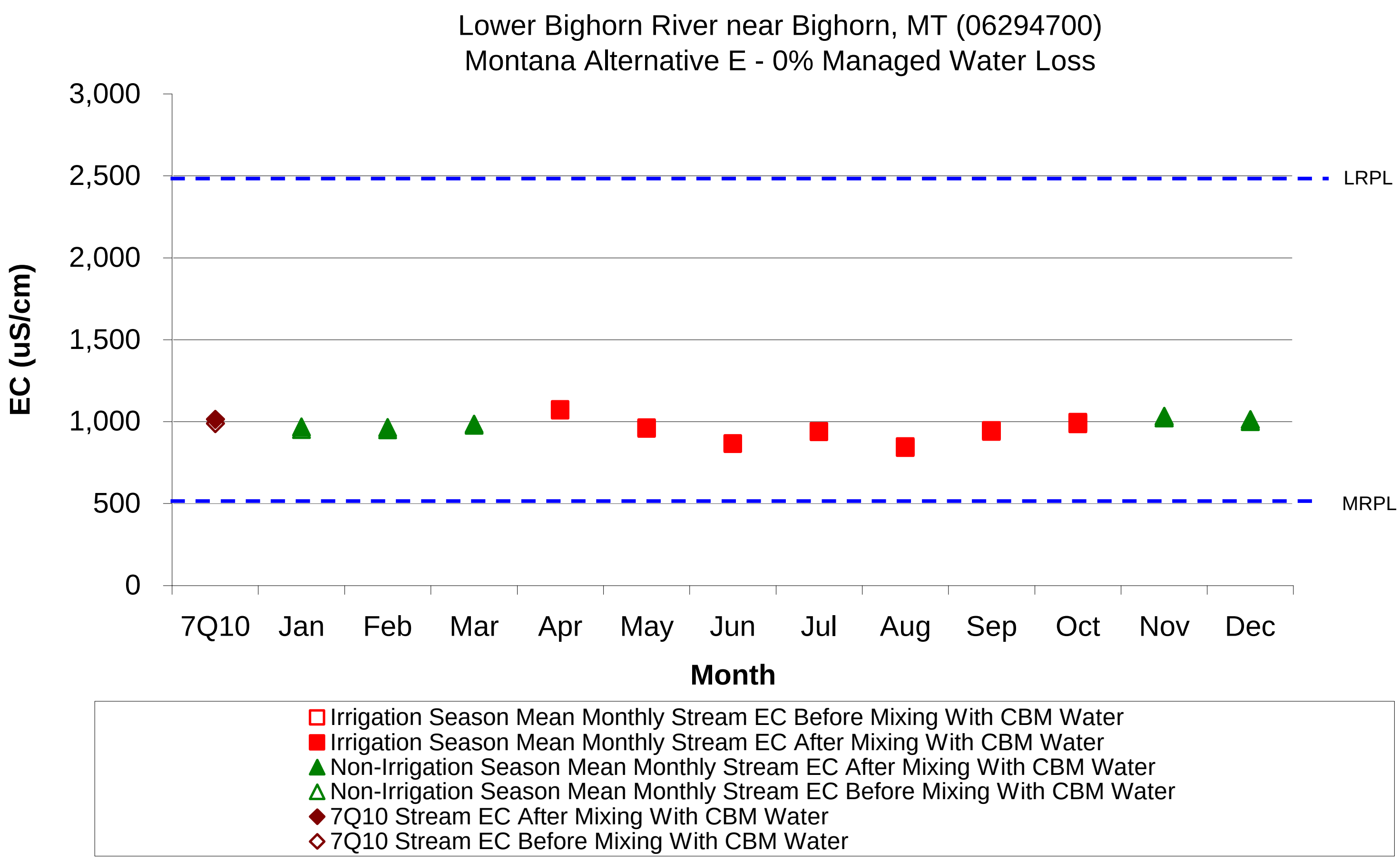


Figure 5-58 Stream SAR Before and After Mixing-Lower Bighorn River Sub-Watershed

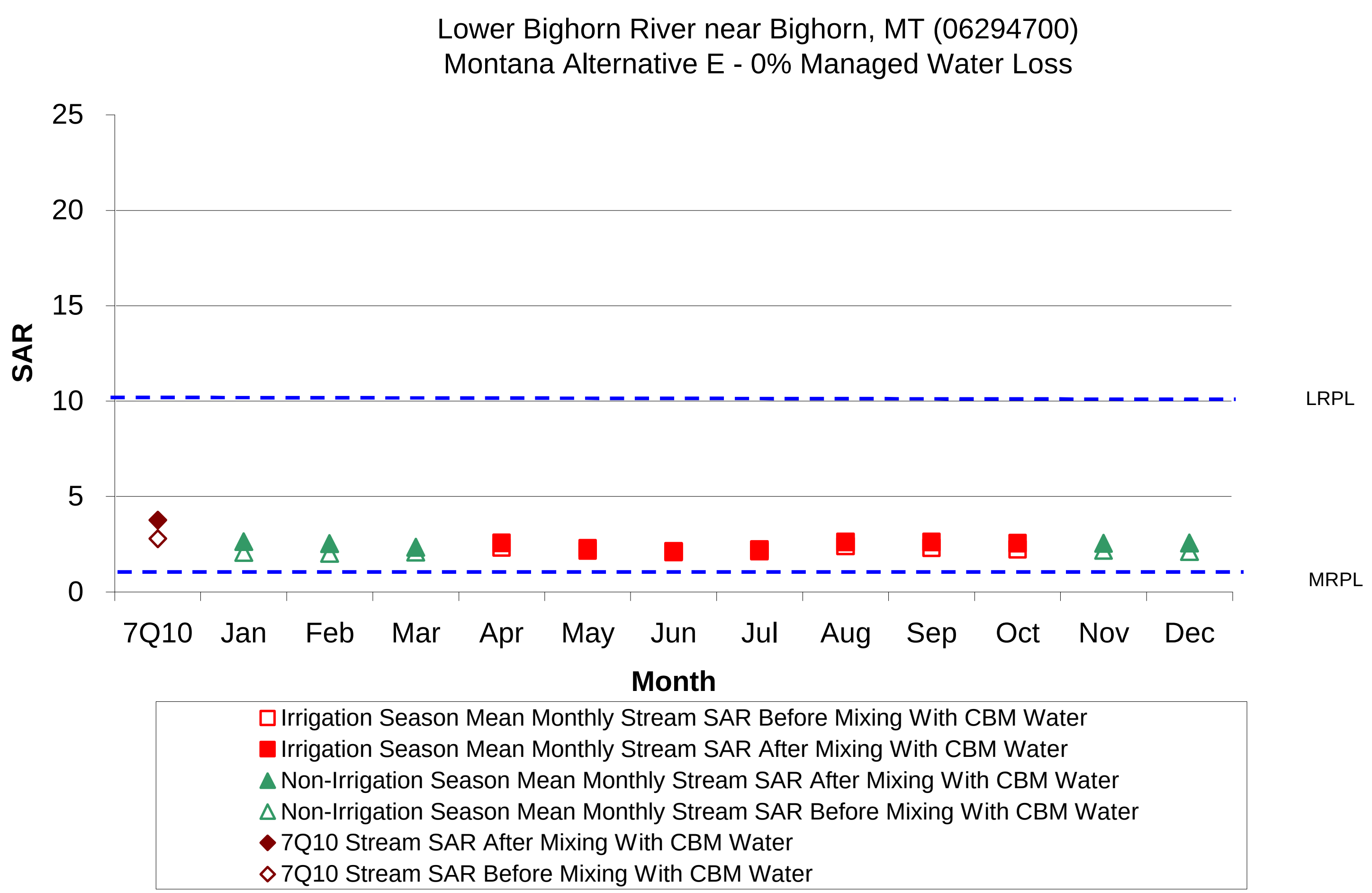


Figure 5-59 Irrigation Suitability Before and After Mixing – Lower Bighorn River Sub-Watershed

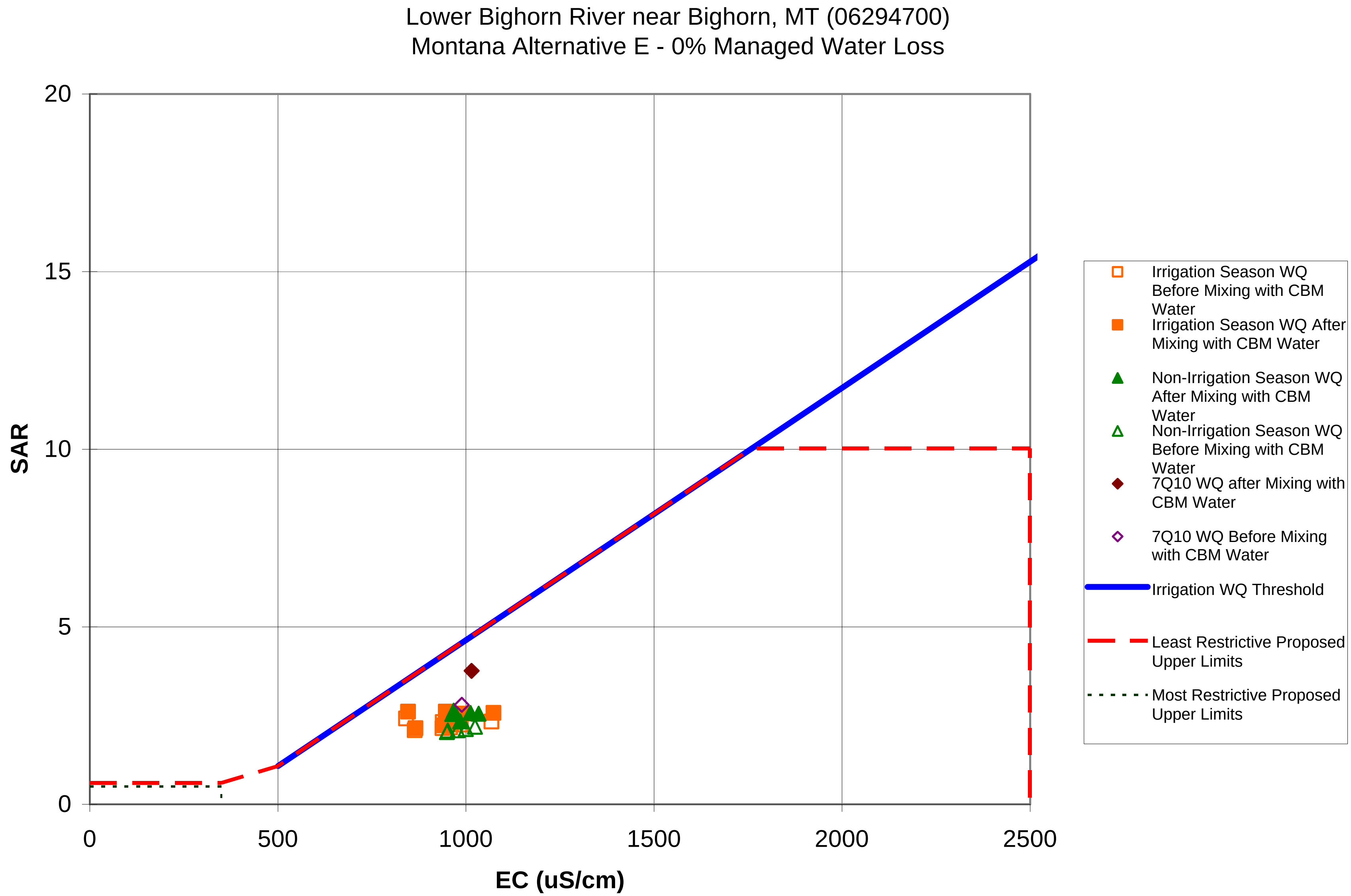
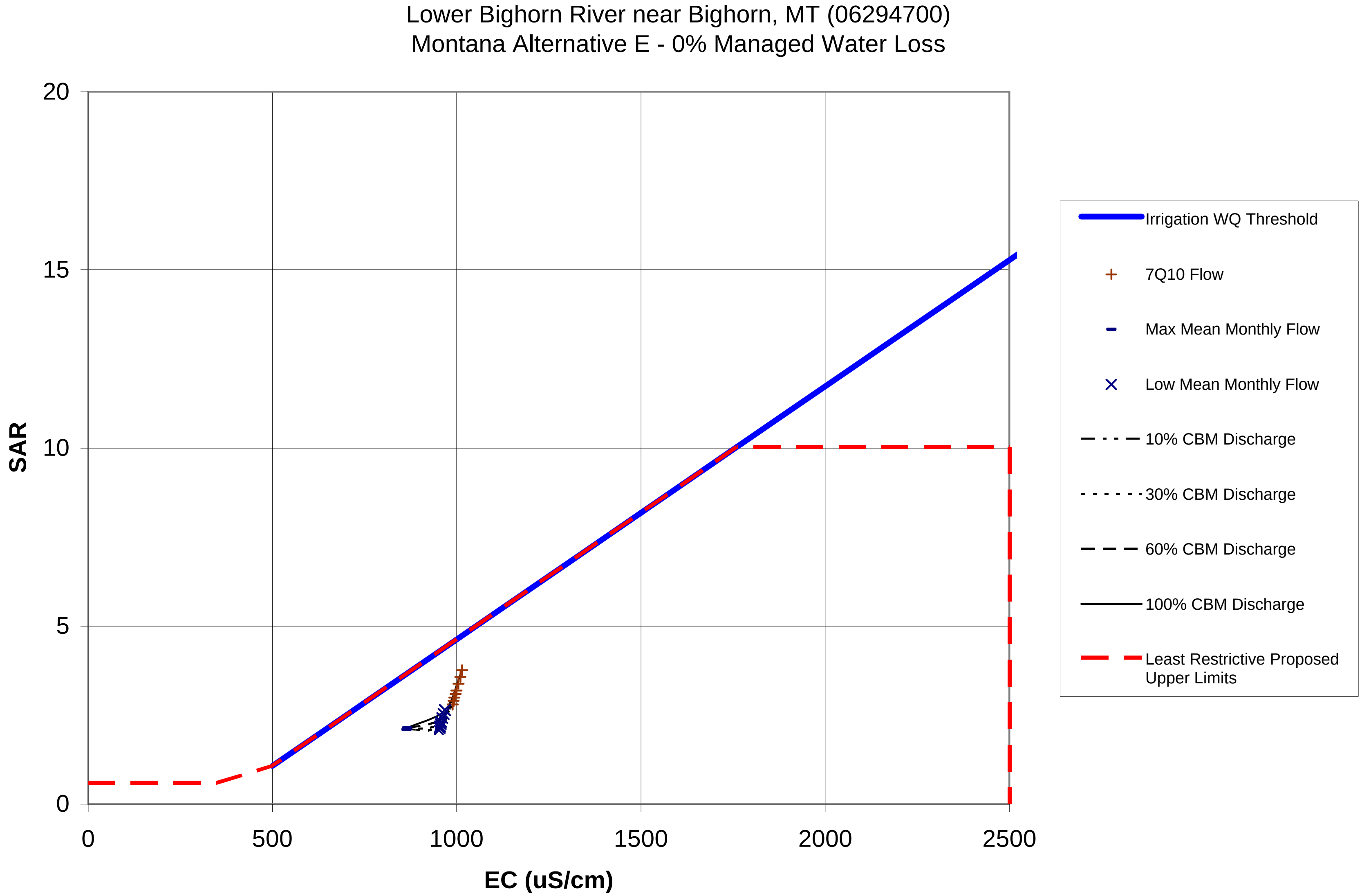


Figure 5-60 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Lower Bighorn River Sub-Watershed



5.3.5 Rosebud Creek

This stream drains part of the area of the PRB in Montana. This stream begins on the Crow Reservation, flows through a portion of Montana and through the Northern Cheyenne Reservation, then through another portion of Montana before it joins the Yellowstone River near Rosebud, Montana. No CBM wells in Wyoming could affect the Rosebud Creek sub-watershed. Table 5-15 below summarizes the predicted effects to water quality for the two stations along Rosebud Creek in Montana.

Table 5-15
Surface Water Impact Analysis of the Rosebud Creek Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
A	Rosebud Creek at Reservation boundary, near Kirby, MT	0.5	500	10	3000	1.78	0.77	1016	1.78	0.77	1016	0.1	1.16	1123	0.1	1.16	1123
	Rosebud Creek at mouth, near Rosebud, MT	0.5	500	10	3000	8.42	4.84	1780	8.42	4.84	1780	0.0	--	--	0.0	--	--
C	Rosebud Creek at Reservation boundary, near Kirby, MT	0.5	500	10	3000	1.78	0.77	1016	22	35.62-43.25	2110-2293	0.1	1.16	1123	20	38.5-46.8	2202-2400
	Rosebud Creek at mouth, near Rosebud, MT	0.5	500	10	3000	8.42	4.84	1780	49	32.85-39.32	2133-2298	0.0	--	--	40	38.7-47.0	2207-2406

Table 5-15
Surface Water Impact Analysis of the Rosebud Creek Sub-Watershed

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
D	Rosebud Creek at Reservation boundary, near Kirby, MT	0.5	500	10	3000	1.78	0.77	1016	22	0.77	1016	0.1	1.16	1123	20	0.54	913
	Rosebud Creek at mouth, near Rosebud, MT	0.5	500	10	3000	8.42	4.84	1780	48	4.84	1780	0.0	--	--	40	1.76	1071
E	Rosebud Creek at Reservation boundary, near Kirby, MT	0.5	500	10	3000	1.78	0.77	1016	1.78	0.77	1016	0.1	1.16	1123	0.1	1.16	1123
	Rosebud Creek at mouth, near Rosebud, MT	0.5	500	10	3000	8.42	4.84	1780	8.42	4.84	1780	0.0	--	--	0.0	--	--

Notes:
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

5.3.5.1 Alternative A

Under this alternative, no CBM water would be discharged into this sub-watershed; therefore, stream water quality and flow will be unchanged. The existing stream water quality can be compared with the following criteria:

- MRPL: Throughout the year, existing monthly averages for EC and SAR at both stations exceed the MRPL for both constituents. The stream could not receive discharges of CBM produced water unless it was of better quality than the stream.
- LRPL: The existing water monthly averages for streams are adequate to meet the LRPL for both constituents throughout the year at both stations.
- Ayers and Westcot diagram: Irrigation with the stream water would not likely cause a reduction in infiltration to soils being irrigated.

All current uses of these waters would be maintained under Alternative A.

5.3.5.2 Alternative C

Under Alternative C, effects to this stream would result from CBM discharges on the reservations or in Montana. Flows would increase by an order of magnitude with CBM discharge, and water quality would be more representative of the CBM discharged water than of the existing stream water quality because there is so little water in the Rosebud Creek naturally. The resultant stream water quality near Kirby, Montana, can be compared with the following criteria:

- MRPL: Figures 5-61 and 5-62 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Rosebud Creek sub-watershed, as modeled at the USGS gauging station near Kirby, Montana. Throughout the year, existing monthly averages for EC and SAR at both stations exceed the MRPL for both constituents. The stream could not receive CBM discharges unless the water was of better quality than the stream.
- LRPL: The resultant stream water quality at Kirby would exceed the LRPL for SAR but would be below the LRPL for EC.
- Ayers-Westcot diagram: Figure 5-63 illustrates the suitability for irrigation of Rosebud Creek near Kirby before and after the creek mixes with discharges of CBM produced water.A comparison of the resultant quality of the mixed water under modeled conditions with the Ayers-Westcot diagram in Figure 5-63 indicates some reduction in infiltration during all months of the irrigation season and under 7Q10 flow conditions. Figure 5-64 illustrates the relationship between EC and SAR in Rosebud Creek near Kirby after the creek mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, a small fraction of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-61 Stream EC Before and After Mixing-Rosebud Creek Sub-Watershed

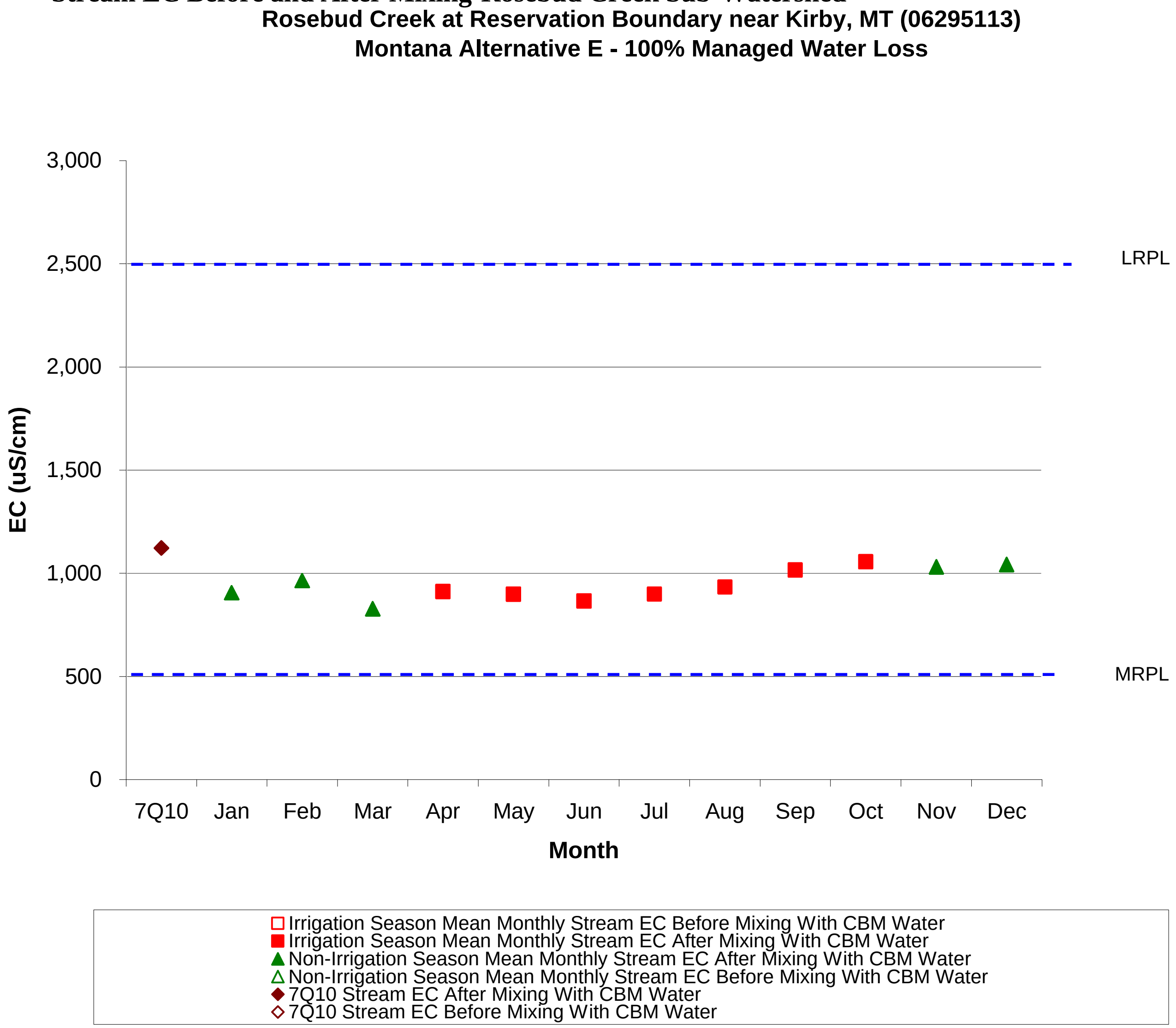


Figure 5-62 Stream SAR Before and After Mixing- Rosebud Creek Sub-Watershed

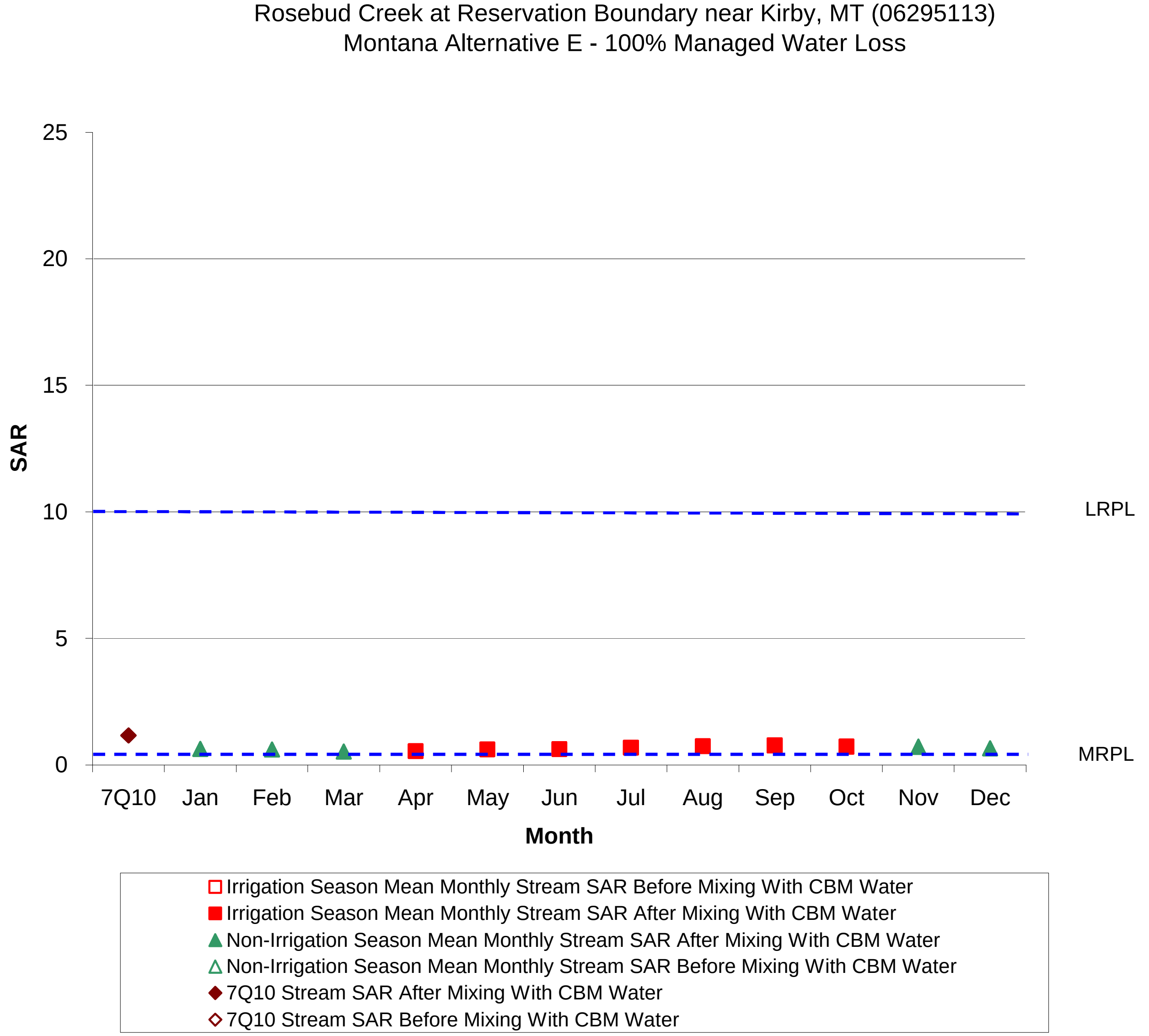


Figure 5-63 Irrigation Suitability Before and After Mixing – Rosebud Creek Sub-Watershed

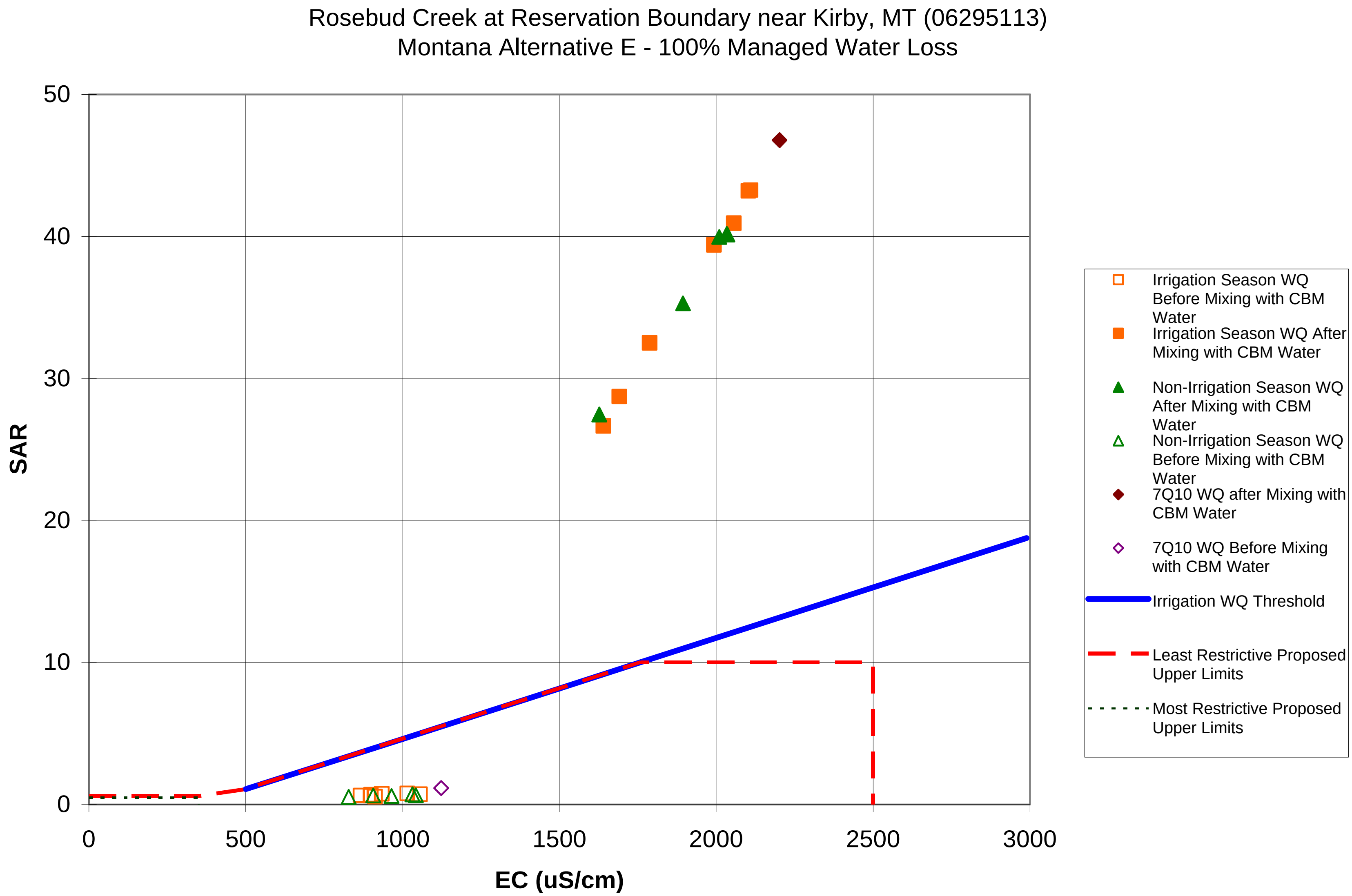
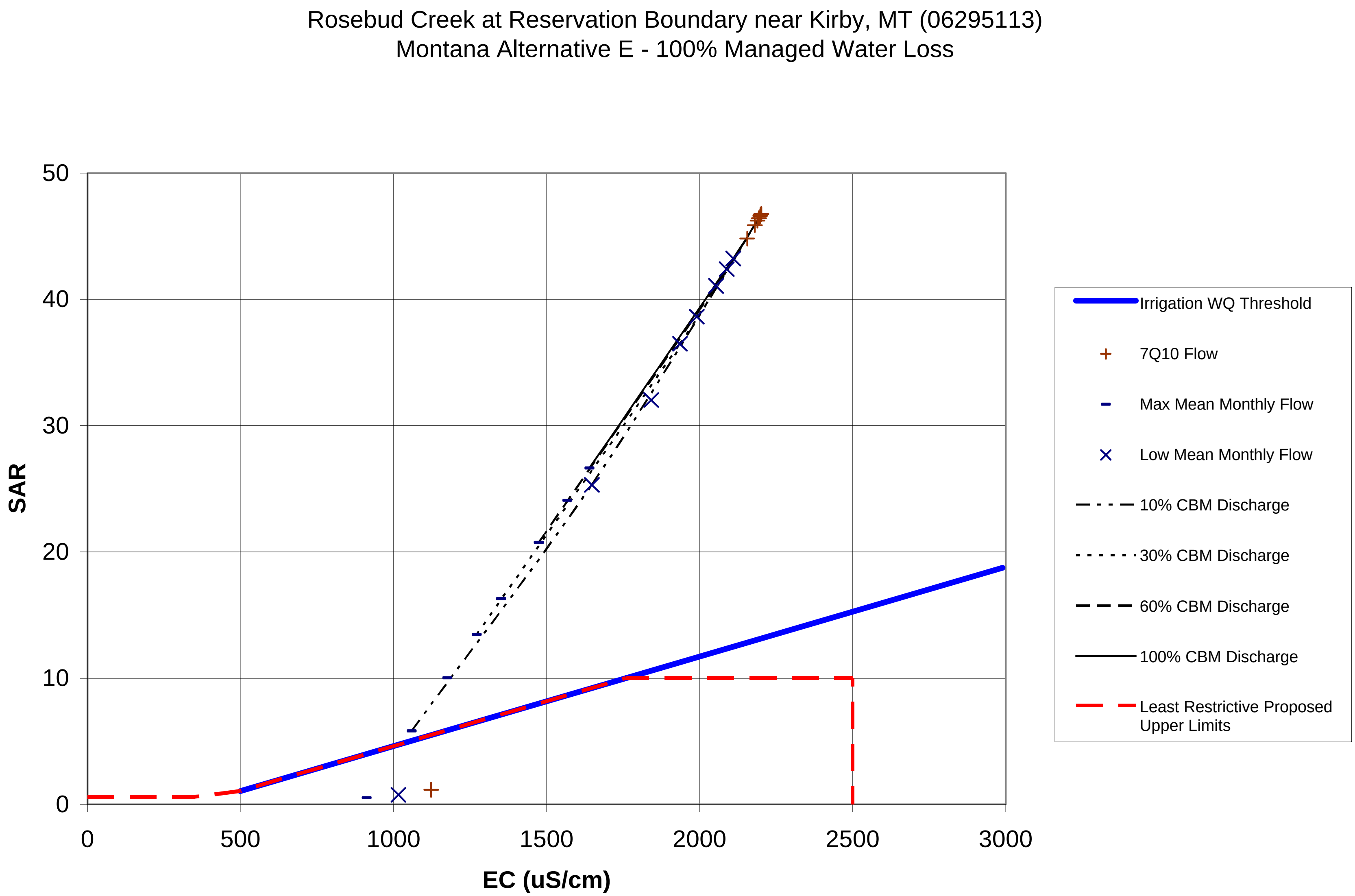


Figure 5-64 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Rosebud Creek Sub-Watershed



Under Alternative C, the resultant stream water quality near Rosebud, Montana can be compared with the following criteria:

- MRPL: Figures 5-65 and 5-66 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Rosebud Creek sub-watershed, as modeled at the USGS gauging station near Rosebud, Montana. Throughout the year, existing monthly averages for EC and SAR at both stations exceed the MRPL for both constituents. The stream could not receive CBM discharges unless the water was of better quality than the stream.
- LRPL: The resultant water quality in the stream at Rosebud would exceed the LRPL for SAR but would be below the LRPL for EC.
- Ayers-Westcot diagram: Figure 5-67 illustrates the suitability for irrigation of the Rosebud Creek near Rosebud before and after mixing with discharges of CBM produced water.A comparison of the resultant quality of the mixed water under modeled conditions with the Ayers-Westcot diagram in Figure 5-67 indicates that the quality of the mixed water at Rosebud would likely cause severe infiltration impacts to irrigated soils during all months of the year. Figure 5-68 illustrates the relationship between EC and SAR in Rosebud Creek near Rosebud after the creek mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, only as small traction (<10 percent) of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-65 Stream EC Before and After Mixing- Rosebud Creek Sub-Watershed

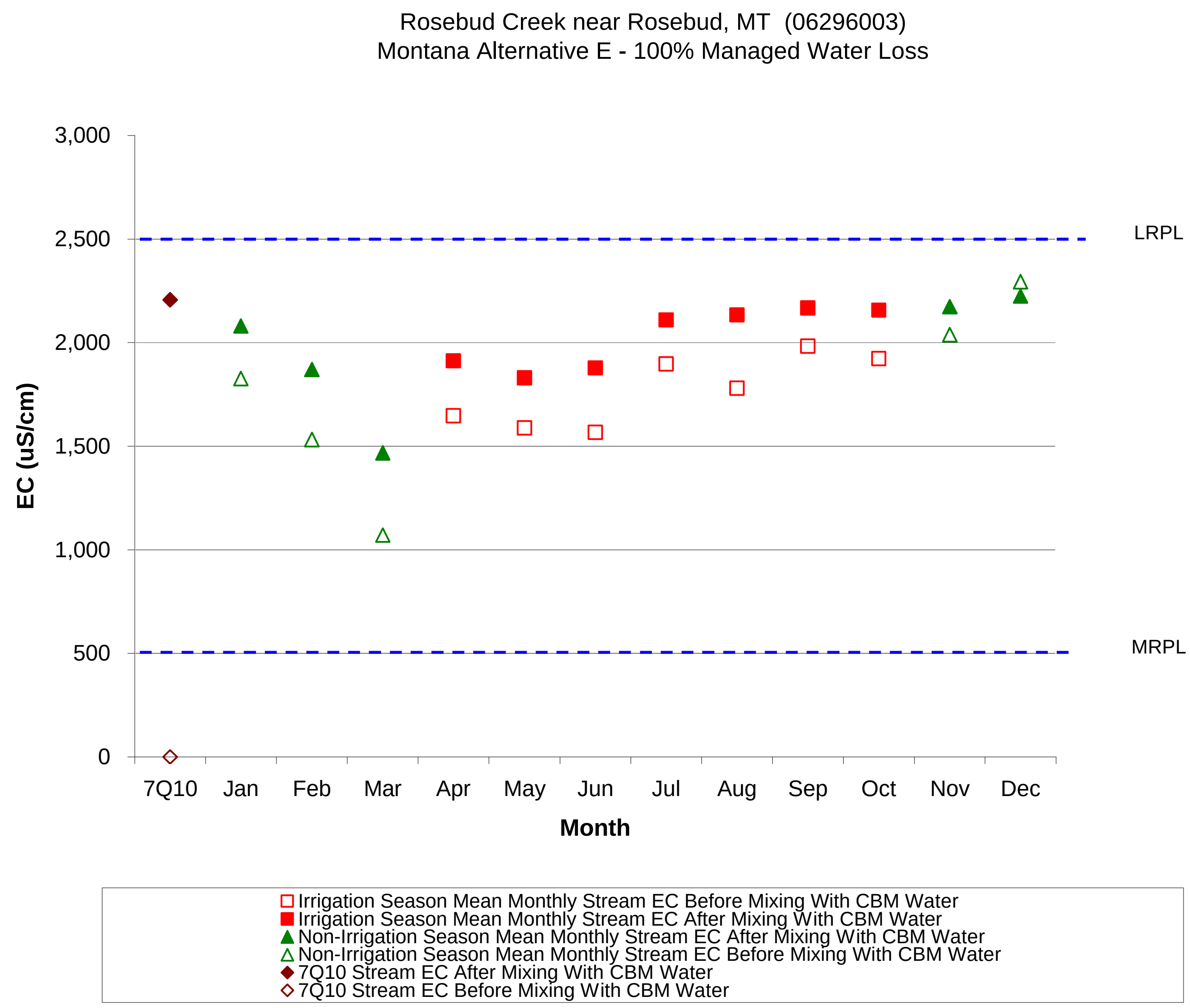


Figure 5-66 Stream SAR Before and After Mixing- Rosebud Creek Sub-Watershed

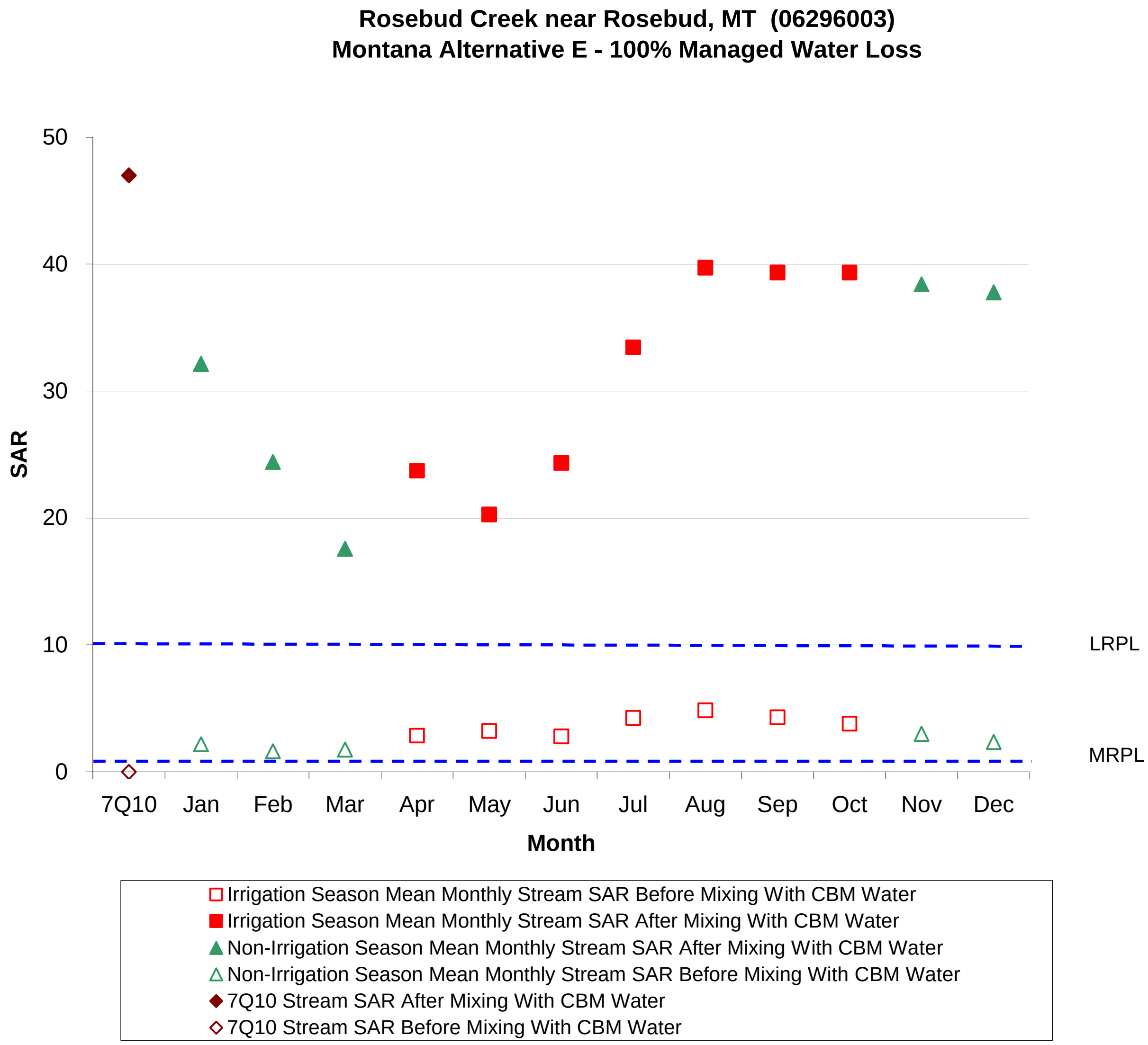


Figure 5-67 Irrigation Suitability Before and After Mixing – Rosebud Creek Sub-Watershed

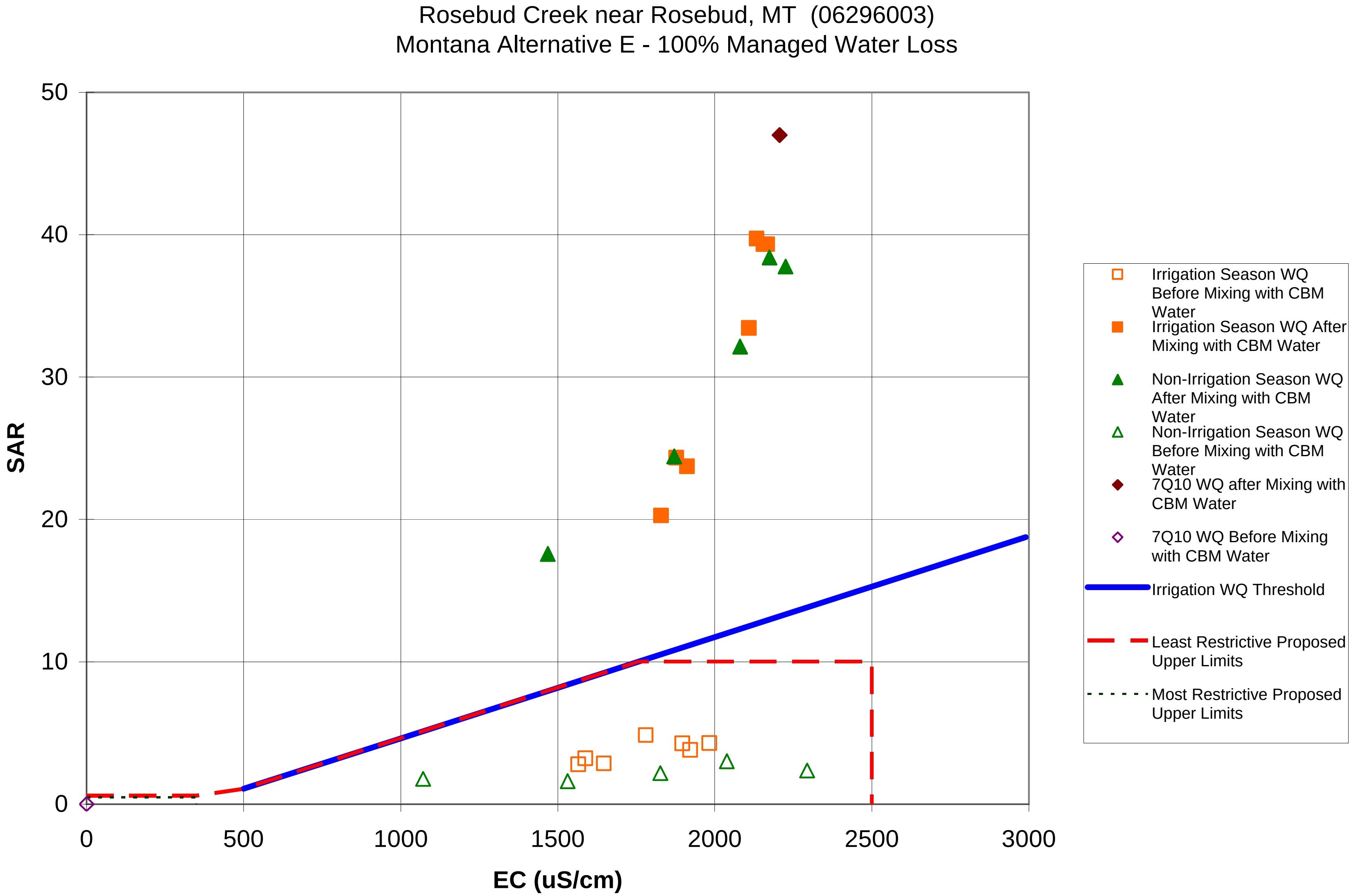
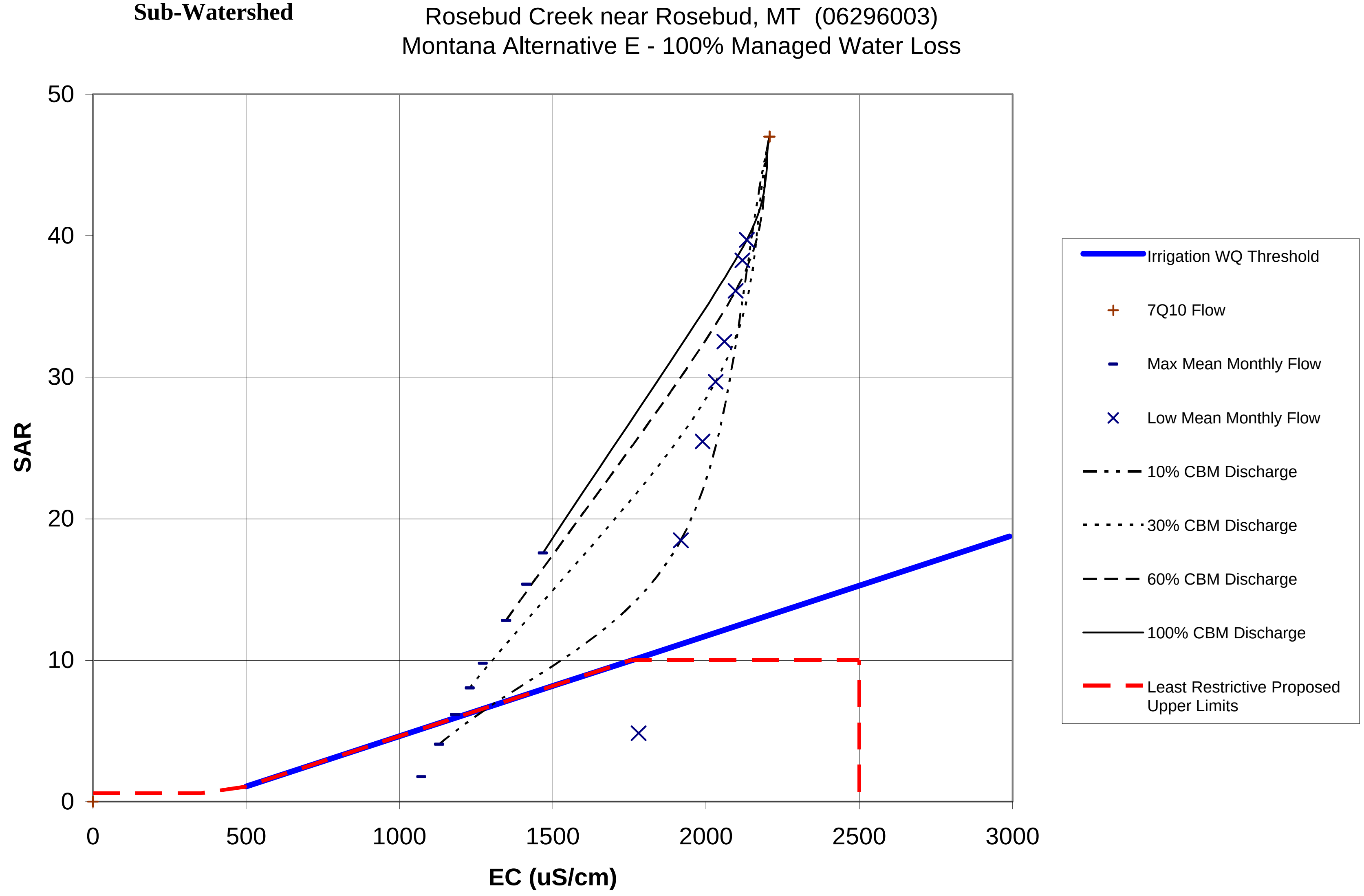


Figure 5-68 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Rosebud Creek Sub-Watershed



Under Alternative C the surface water quality in Rosebud Creek in Montana would be reduced, resulting in severe curtailment of use of this water for irrigation.

5.3.5.3 Alternative D

Under Alternative D, 20 percent of produced water would be used for beneficial uses, and the remaining 80 percent would be treated to the pre-development quality of the surface water before discharge.

Changes in volume of flow are a result of treated and untreated discharges in Montana. Effects on surface water from Montana CBM development are caused by the increases in base flow.

5.3.5.4 Preferred Alternative E

Rosebud Creek is not expected to be affected by CBM wells in Wyoming, and because Rosebud Creek contains high-quality water at low flow rates, there is expected to be no discharge of CBM water from Montana into Rosebud Creek under the Preferred Alternative E.

The effects to the Rosebud Creek under this alternative would be the same as were described for Alternative A since no additional CBM discharge in Montana to Rosebud Creek would be allowed. One hundred percent of the CBM produced water would be managed by other methods in the Rosebud Creek sub-watershed.

5.3.6 Yellowstone River

The Yellowstone River drains all of the Montana watersheds in the PRB. It provides a predictor of the cumulative effects forecast from CBM development in Montana and Wyoming in the Bighorn, Rosebud, Tongue, and Powder watersheds. The Forsyth station would be affected by CBM discharges into the Bighorn, Little Bighorn, and Rosebud watersheds. The Sidney station would be affected by all CBM development in Montana, and from CBM development in Wyoming that occurs in the Tongue, Powder, and Little Powder watersheds. Table 5-16 below summarizes the impacts for two stations along the Lower Yellowstone River in Montana.

Table 5-16
Surface Water Impact Analysis of the Lower Yellowstone-Sunday/Lower Yellowstone Sub-Watersheds

		MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
Alternative	**Station**	**SAR**	**EC (µS/cm)**	**SAR**	**EC (µS/cm)**	**Flow (cfs)**	**SAR**	**EC (µS/cm)**	**Flow (cfs)**	**SAR**	**EC (µS/cm)**	**Flow (cfs)**	**SAR**	**EC (µS/cm)**	**Flow (cfs)**	**SAR**	**EC (µS/cm)**
A	Yellowstone River at Forsyth, MT	0.5	500	10	2500	5820	1.99	745	5820	1.99	745	NA	NA	NA	NA	NA	NA
	Yellowstone River near Sidney, MT	0.5	500	10	2500	5764	2.00	870	5805	2.26	881	2240	2.52	809	2281	3.17	838
C	Yellowstone River at Forsyth, MT	0.5	500	10	2500	5820	1.99	745	5831	2.06-2.08	748	NA	NA	NA	NA	NA	NA
	Yellowstone River near Sidney, MT	0.5	500	10	2500	5764	2.00	870	5945	3.12-3.31	912-917	2240	2.52	809	2421	5.22-5.70	917-928
D	Yellowstone River at Forsyth, MT	0.5	500	10	2500	5820	1.99	745	5831	1.99	745	NA	NA	NA	NA	NA	NA
	Yellowstone River near Sidney, MT	0.5	500	10	2500	5764	2.00	870	5805	2.23	870	2240	2.52	809	2421	3.06	814

Table 5-16
Surface Water Impact Analysis of the Lower Yellowstone-Sunday/Lower Yellowstone Sub-Watersheds

Alternative	Station	MRPL		LRPL		Existing Stream Water Quality at Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality at 7Q10 Flow			Resulting Stream Water Quality at 7Q10 Flow		
		SAR	EC (µS/cm)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)	Flow (cfs)	SAR	EC (µS/cm)
E	Yellowstone River at Forsyth, MT	0.5	500	10	2500	5820	1.99	745	5831	2.06	748	NA	NA	NA	NA	NA	NA
	Yellowstone River near Sidney, MT	0.5	500	10	2500	5764	2.00	870	5850	2.54	893	2240	2.52	809	2421	5.22-5.70	917-928

Notes:
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
µS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.
NA = Not Applicable

5.3.6.1 Alternative A

Only the station at Sidney is expected to receive CBM-related effects under Alternative A. These effects would result from discharges from CX Ranch wells in Montana and CBM wells in Wyoming. After the water mixes, the resultant flow under low monthly flow conditions would increase slightly. The resultant EC and SAR would increase from existing stream conditions. The resultant water quality in the stream can be compared with the following criteria:

- MRPL: The water quality in the Yellowstone River naturally exceeds the MRPL for SAR; and therefore could not receive additional CBM discharges if these limits were adopted. The effects forecast under this alternative would cause the stream water to further exceed these limits.
- LRPL: The resultant water quality would be adequate to meet the LRPL for EC and SAR during even the lowest flow periods.
- Ayers and Westcot diagram: Irrigation with the mixed water would not cause infiltration impacts to irrigated soils.

The volume and quality of surface water in the Yellowstone River would not be appreciably affected by discharges from Montana and Wyoming under Alternative A. Discharges of CBM water would only slightly increase surface water flow in the Yellowstone River, causing negligible changes to water quality, even during historically low-flow periods.

5.3.6.2 Alternative C

Because of the significant volume of water in the Yellowstone River to dilute the water that would be discharged by CBM production in both Montana and Wyoming, the resultant water quality would show only slight changes in both EC and SAR. The resultant water quality can be compared with the following criteria:

- MRPL: The existing water quality in the Yellowstone River naturally exceeds the MRPL for EC and SAR during all months of the year and would not be able to receive additional CBM discharges if these limits were adopted. The impacts forecast from Wyoming and Montana CBM water under Alternative C would also exceed these limits.
- LRPL: The resultant water quality would be adequate to meet these limits.
- Ayers and Westcot diagram: Irrigation with the mixed water would not cause infiltration impacts to irrigated soils at any time. As stated previously, it is important to be mindful of an upper bound on the Ayers-Westcot relationship in reviewing the conclusions reached under this alternative. This may help explain the situation where the MRPL (or perhaps, the LRPL) shows a potential effect, where the Ayers-Westcot diagram indicates no reduction in infiltration.

Under Alternative C, the quality of surface water in the Yellowstone River in Montana would be slightly reduced; however, no changes should be required in irrigation management practices by downstream users for continued use of this water. The resultant water quality in the Lower Yellowstone River is sufficient for irrigation even during the months with the lowest flows.

5.3.6.3 Alternative D

Under Alternative D, 20 percent of produced water would be used for beneficial uses, and the remaining 80 percent would be treated to the pre-development quality of the surface water before discharge.

The increases in the quality of surface water for Alternative D would result from discharge of untreated CBM water from CBM development in Wyoming. Changes in the volume of flow would result from treated and untreated discharges in both Montana and Wyoming. The effects that originate from Wyoming would be the same as were described under Alternative A. Effects on surface water from CBM development in Montana would be caused by the increases in base flow.

5.3.6.4 Preferred Alternative E

The Yellowstone River receives the combined flows of the other watersheds in the PRB. The Forsyth Station is upstream, which receives no contribution from discharges in Wyoming but will receive some CBM discharge from Montana. The Sidney station is the downstream station and receives discharges from all CBM wells in the Montana portion of the PRB. It also receives discharges from 25,538 CBM wells in Wyoming. The resultant stream water quality near Forsyth, Montana, can be compared with the following criteria:

- MRPL: Figures 5-69 and 5-70 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly and 7Q10 flow conditions would exceed the MRPL and LRPL considered for water quality in the Lower Yellowstone sub-watershed, as modeled at the USGS gauging station near Forsyth, Montana. The water quality in this stream is naturally above the MRPL for EC and SAR during several months; therefore, the stream would not be able to receive additional CBM discharges if these limits were adopted. The effects forecast from CBM development would further exceed these proposed limits.
- LRPL: The water quality at the Forsyth station during 7Q10 flow conditions is above the LRPL for SAR.
- Ayers-Westcot diagram: Figure 5-71 illustrates the suitability for irrigation of the Yellowstone River near Forsyth before and after the river mixes with Discharges of CBM produced water.A comparison of the resultant quality of the mixed water under modeled conditions with the Ayers-Westcot diagram in Figure 5-71 indicates no reduction in infiltration. Figure 5-72 illustrates the relationship between EC and SAR in Rosebud Creek near Kirby after the creek mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially 100 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-69 Stream EC Before and After Mixing-Lower Yellowstone River Sub-Watershed

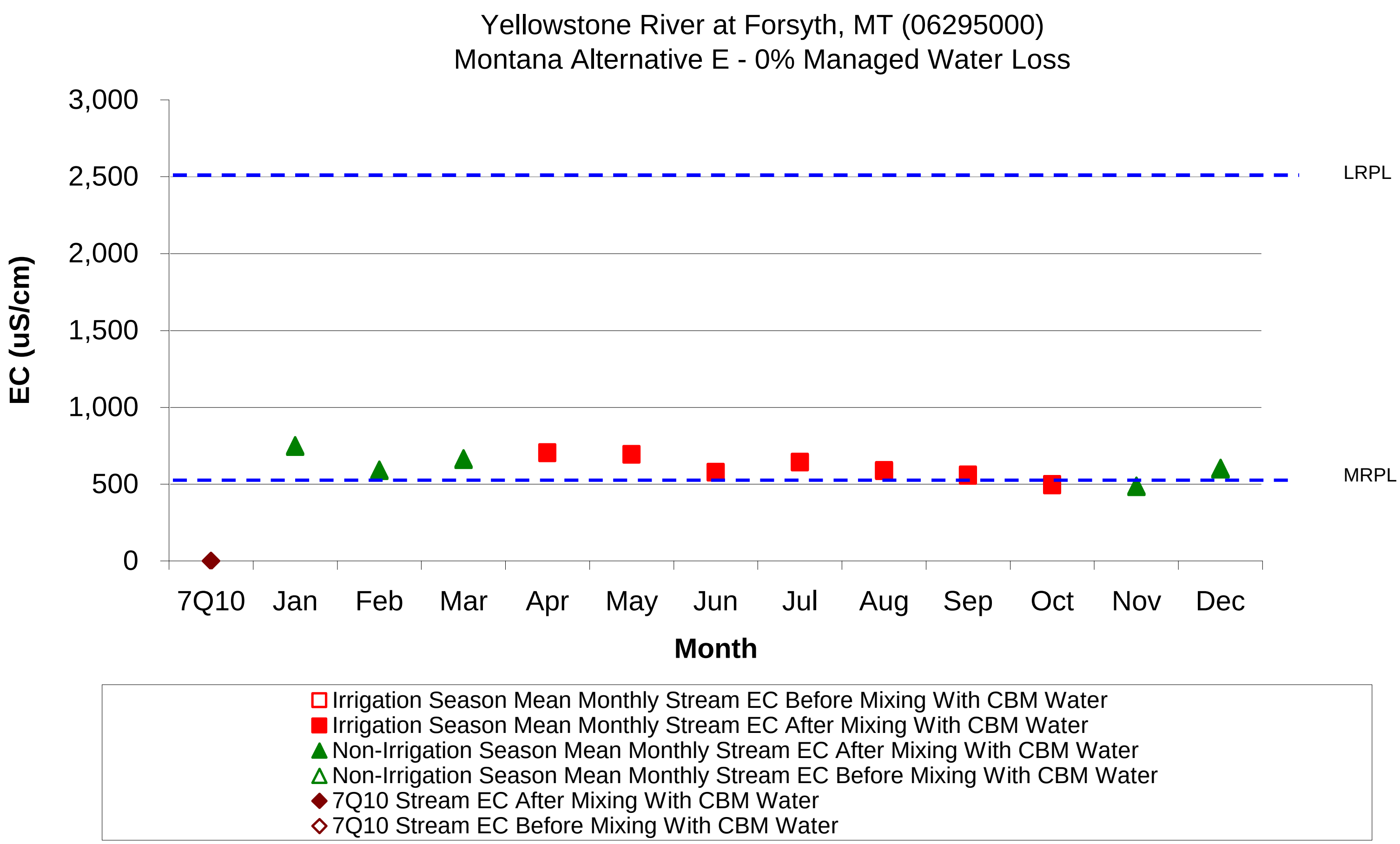


Figure 5-70 Stream SAR Before and After Mixing- Lower Yellowstone River Sub-Watershed

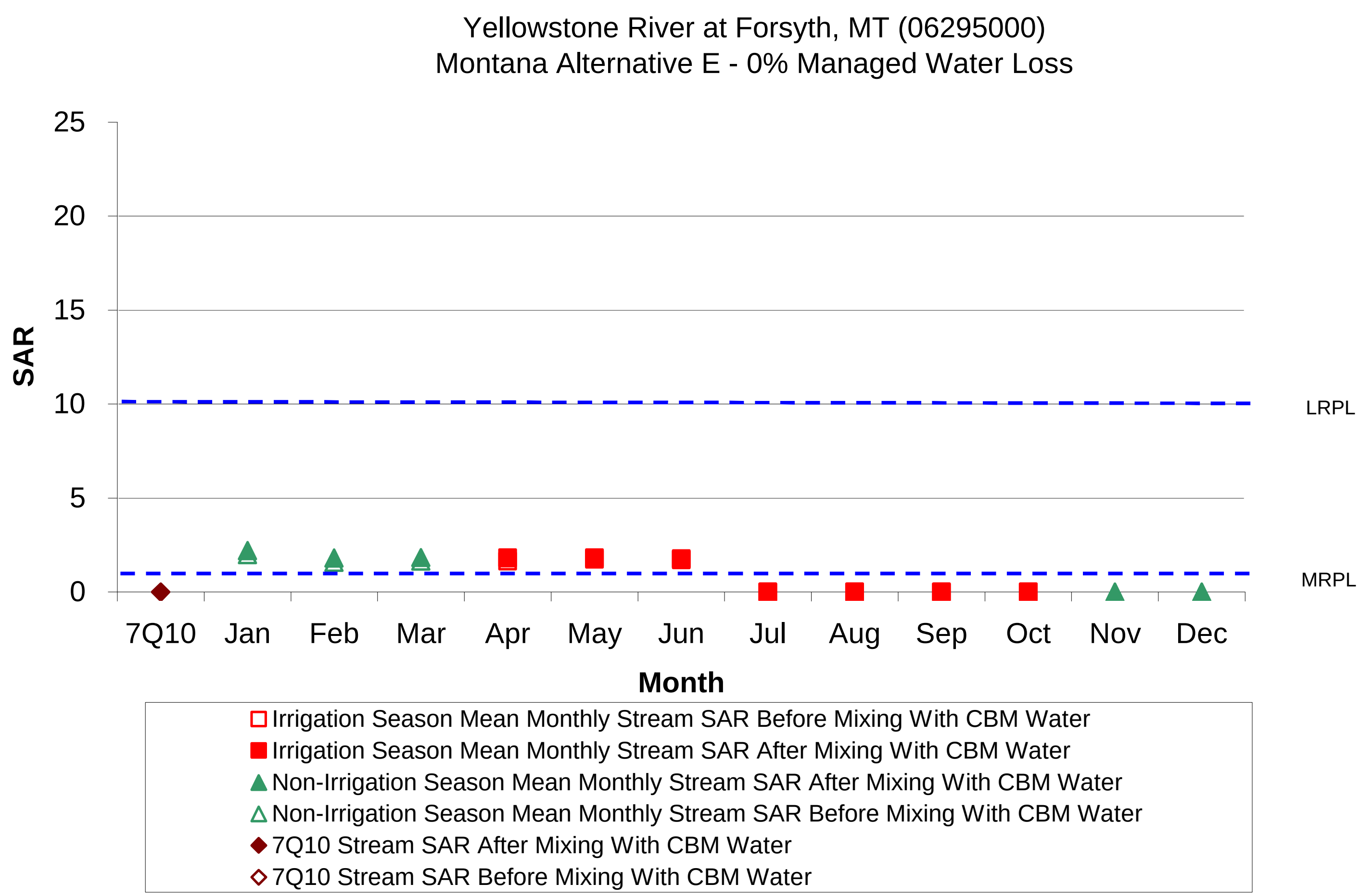


Figure 5-71 Irrigation Suitability Before and After Mixing – Lower Yellowstone River Sub-Watershed

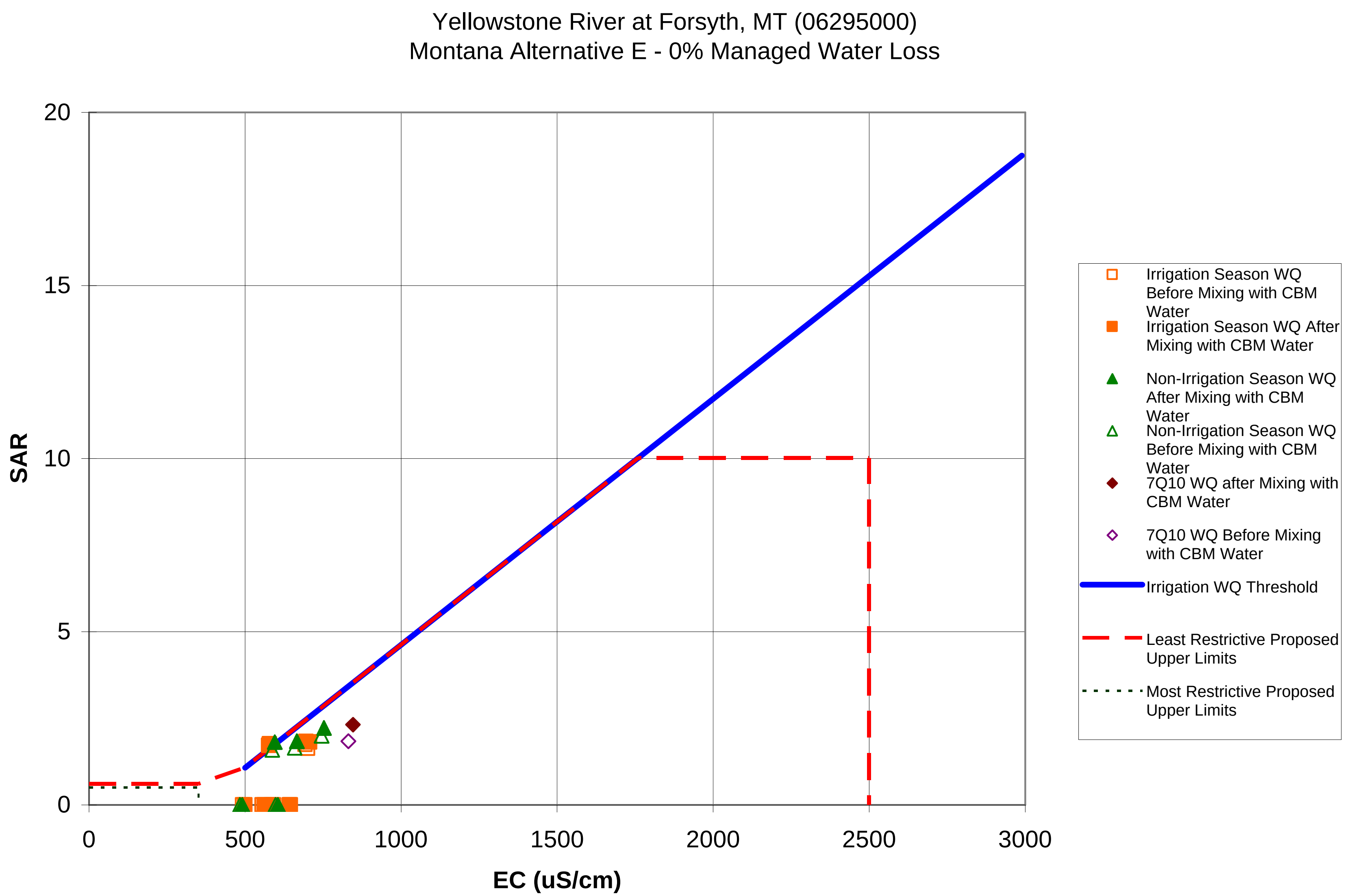
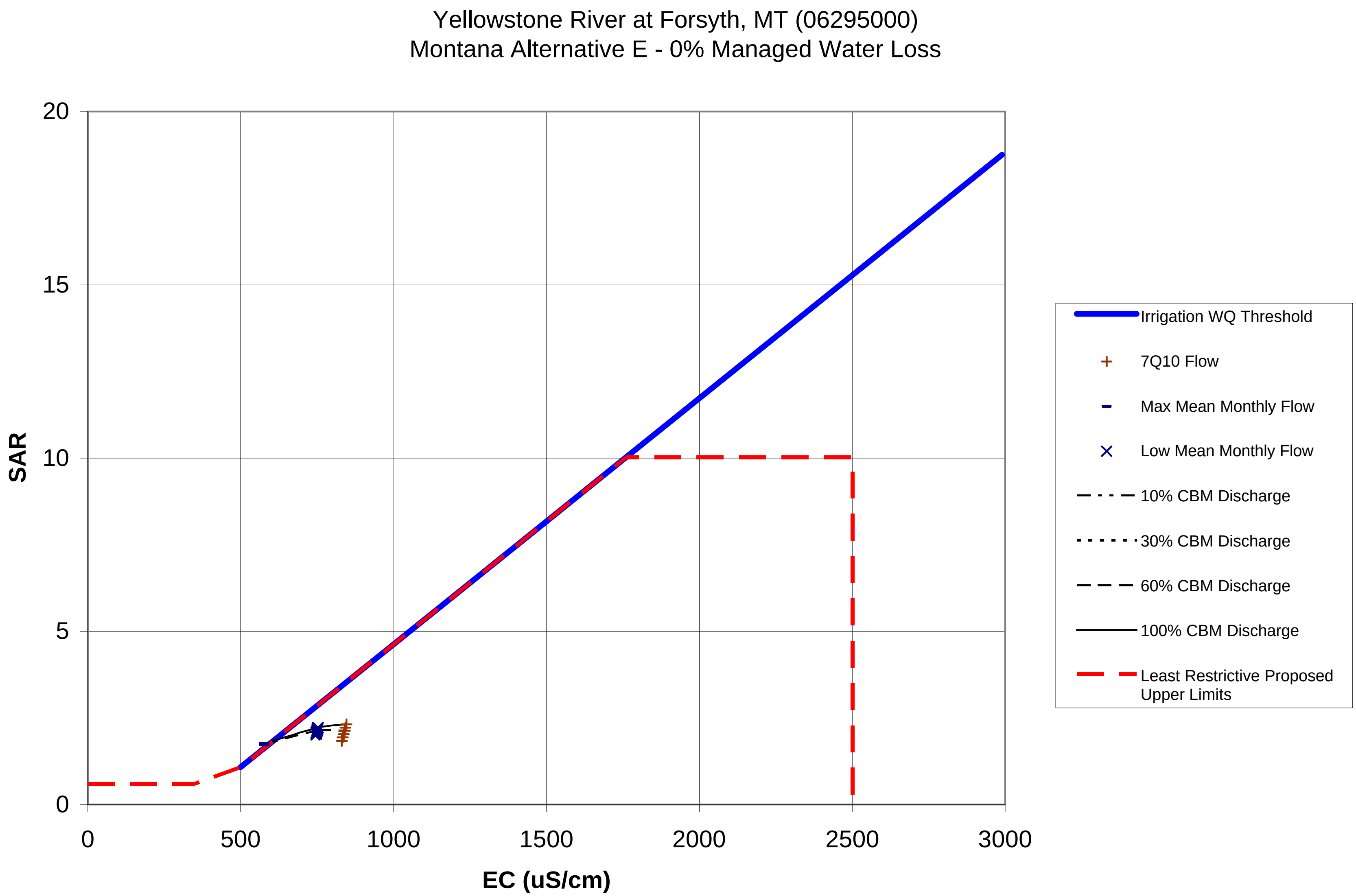


Figure 5-72 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Lower Yellowstone River Sub-Watershed



Under Alternative E, the resultant stream water quality near Sydney, Montana can be compared with the following criteria:

- MRPL: Figures 5-73 and 5-74 are used to illustrate the months during the year when the existing water quality and resultant quality of mixed water during mean monthly flow and 7Q10 flow conditions would exceed the MRPL and LRPL being considered for water quality in the Rosebud Creek sub-watershed, as modeled at the USGS gauging station near Sydney, Montana. The water quality in this stream is naturally above the MRPL for EC and SAR during several months; therefore, the stream would not be able to receive additional CBM discharges if these limits were adopted. The effects forecast from CBM development would further exceed these proposed limits.
- LRPL: The LRPL for EC and SAR would not be exceeded either during the minimum mean monthly flow or during 7Q10 flow conditions.
- Ayers-Westcot diagram: Figure 5-75 illustrates the suitability for irrigation of the Lower Yellowstone River near Sydney before and after the river mixes with discharges of CBM produced water.A comparison of the resultant quality of the mixed water under modeled conditions with the Ayers-Westcot diagram in Figure 5-75 indicates no impacts to infiltration during the low monthly flow and that the mixed water would be adequate for use for irrigation. Figure 5-76 illustrates the relationship between EC and SAR in the Lower Yellowstone River near Sydney after the river mixes with varying proportions of discharges of CBM produced water under various stream flow conditions. Under modeled conditions, essentially 100 percent of the CBM discharge could occur during the low monthly flow without causing effects to infiltration.

Figure 5-73 Stream EC Before and After Mixing- Lower Yellowstone River Sub-Watershed

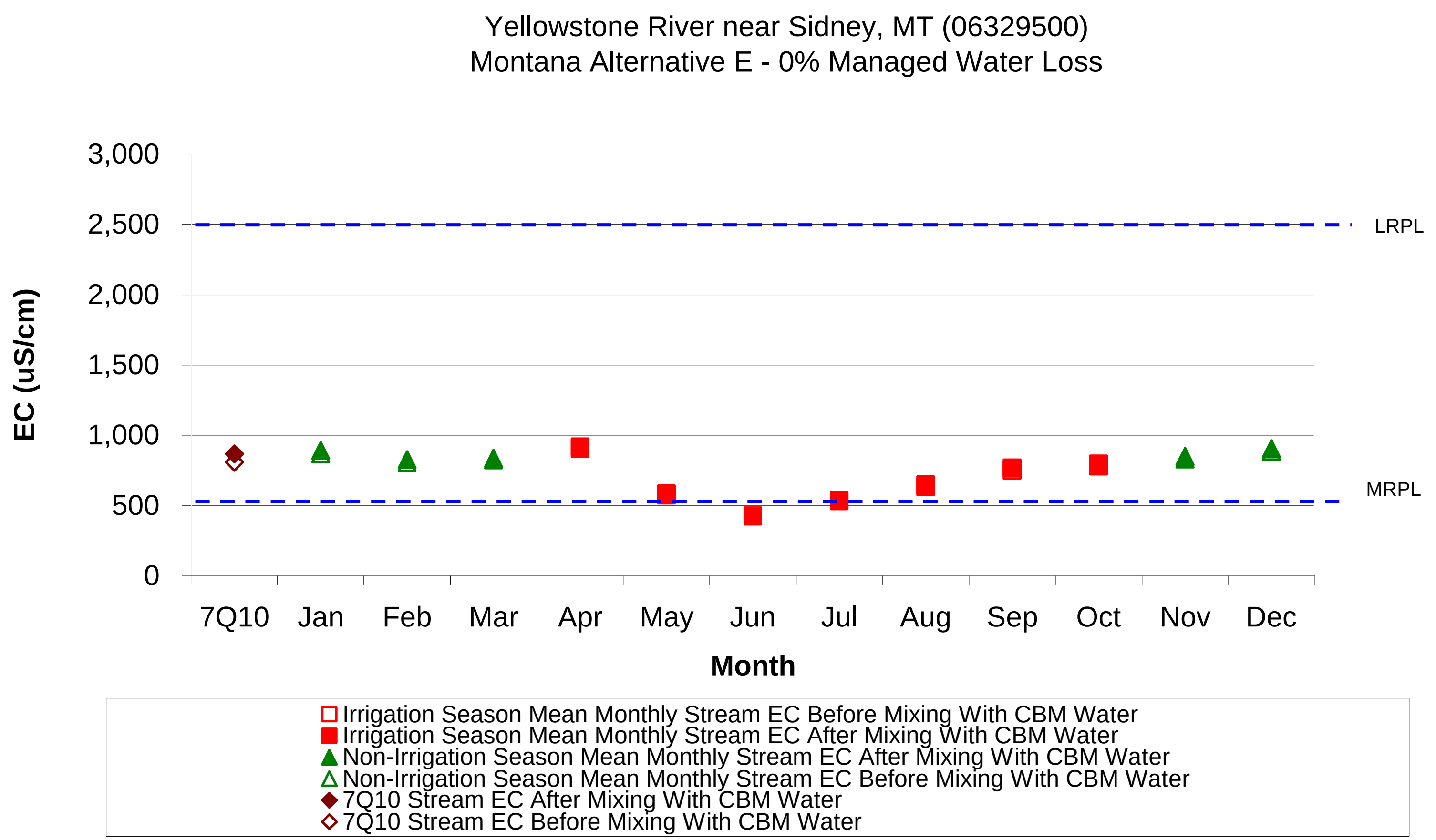


Figure 5-74 Stream SAR Before and After Mixing- Lower Yellowstone River Sub-Watershed

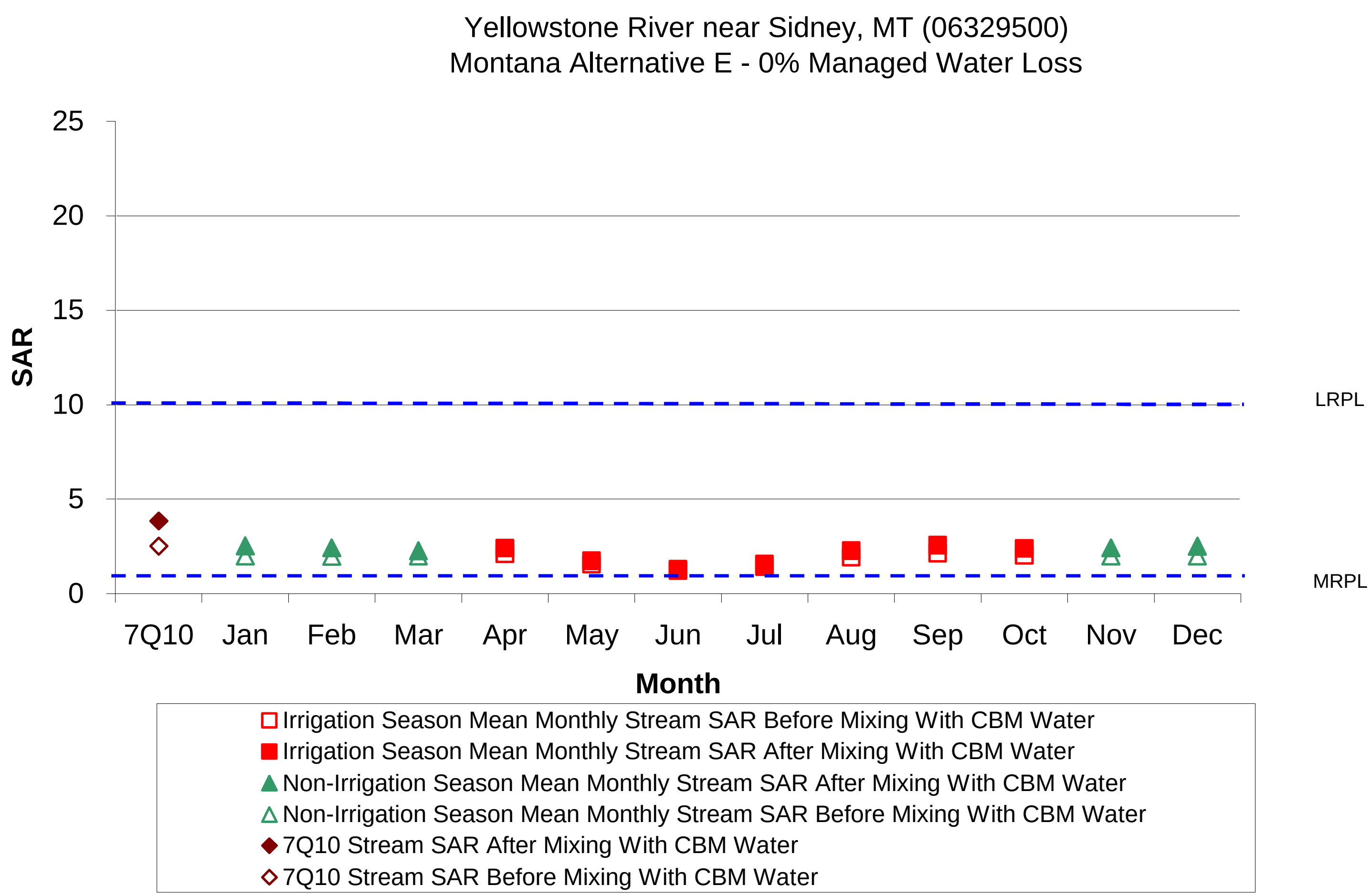


Figure 5-75 Irrigation Suitability Before and After Mixing – Lower Yellowstone River Sub-Watershed

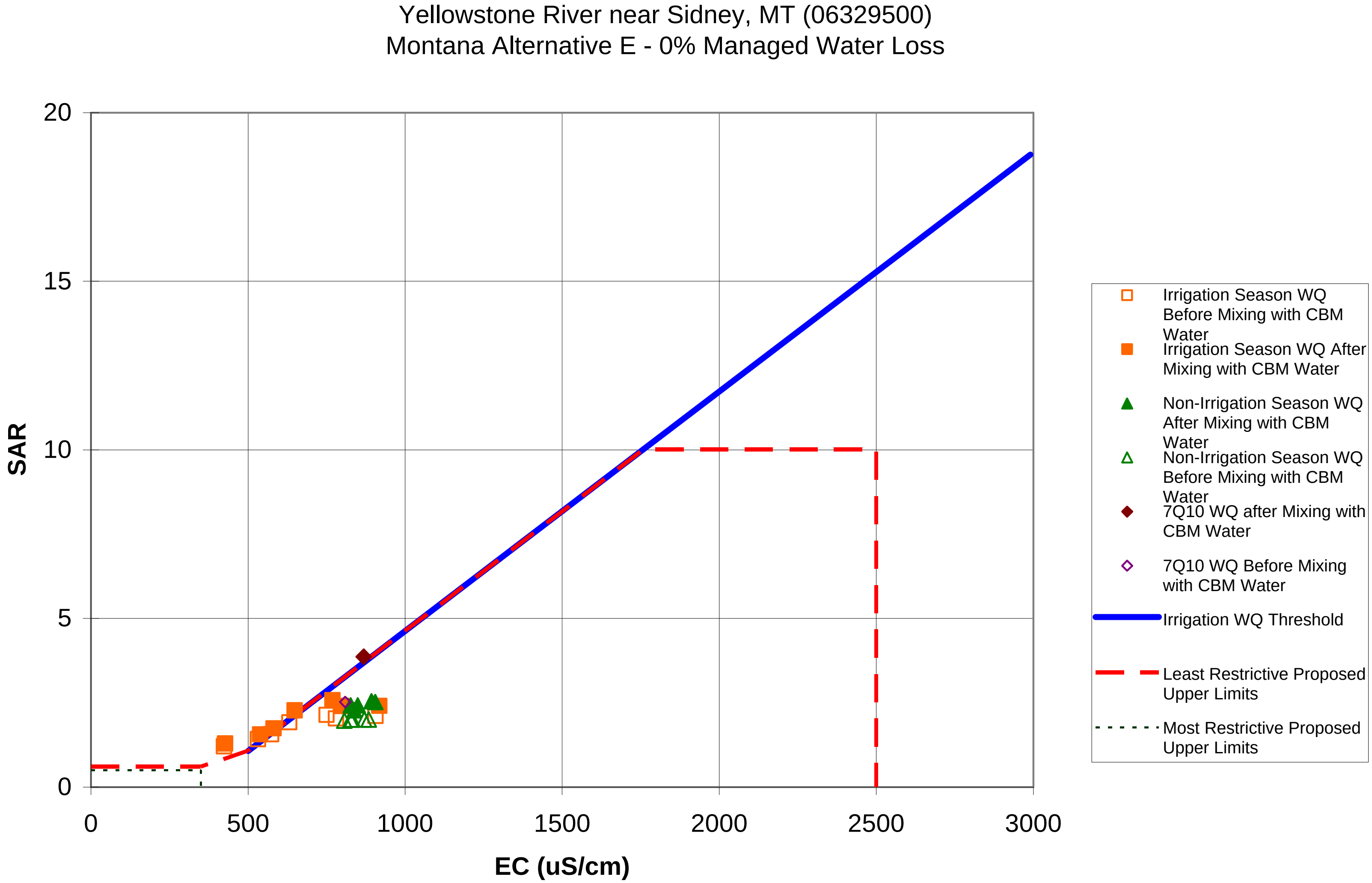
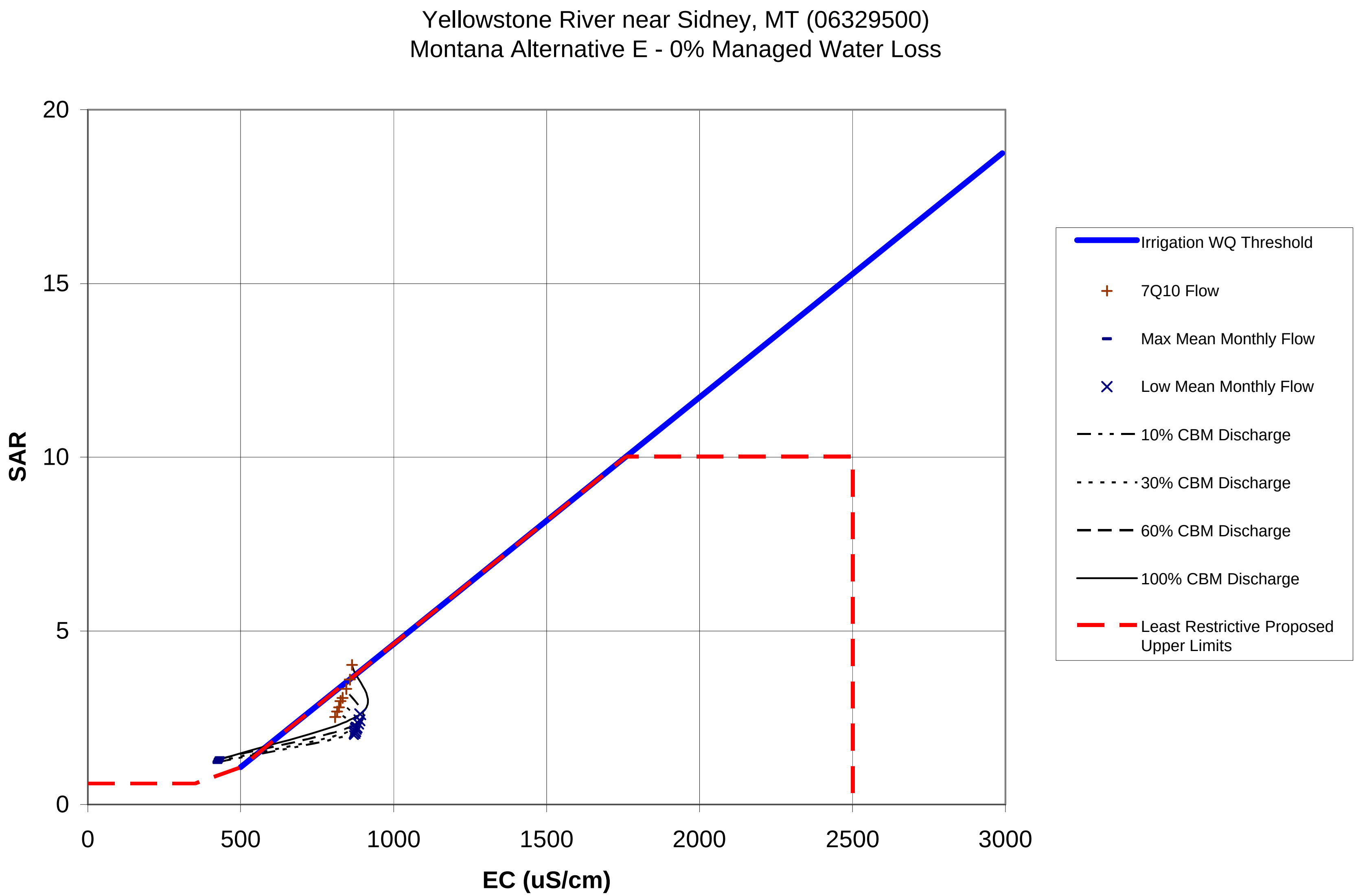


Figure 5-76 Irrigation Suitability Before and After Mixing with Varying Proportions of CBM Discharge – Lower Yellowstone River Sub-Watershed



Although discernable effects may be seen at Forsyth and Sidney, beneficial uses would not be reduced under Preferred Alternative E.

6.0 CUMULATIVE IMPACTS TO SURFACE WATER PROJECTED BY THE MODEL

Results of the cumulative impact analysis in the Powder River Basin under Wyoming's Alternative 2A and Montana's Preferred Alternative E are presented in Table 6-1. The analysis at the Tongue River station near Ashland, Montana, incorporates all existing and future forecast CBM development in the Tongue River watershed from Wyoming and Montana. The analysis at the Powder River station at Locate, Montana, incorporates the existing and future forecast CBM development in the Little Powder and Powder River drainages in Wyoming and the future forecast development in the Montana portion of those drainages. Potential impacts to water quality are discussed below.

After the water mixes, surface water flow in the Tongue River at Ashland, Montana, would increase moderately during low-flow conditions. The resultant water quality in the stream would increase slightly in EC and SAR from existing conditions. The resultant mixed stream water can be compared with the available surface water criteria:

- MRPL: The water quality in the Tongue River at Ashland, Montana currently exceeds the MRPL for EC and SAR; thus, any additional discharge that would reach the main stem would likely cause further degradation in terms of suitability for irrigation if the states and EPA conclude that the MRPL is protective of irrigation uses.
- LRPL: Under modeled conditions, the resultant water quality would be adequate to meet the LRPL for both EC and SAR under mean monthly flow during all months of the year and during 7Q10 flow conditions.
- Ayers and Westcot diagram: Irrigation with the resultant mixed water quality indicates that there is not likely to be a reduction in infiltration during mean monthly or 7Q10 flow conditions. During the low monthly flow, essentially 100 of the CBM discharge could occur without causing potential effects to infiltration.

After the water mixes, surface water flow in the Powder River at Locate, Montana, would increase approximately two-fold during low-flow conditions. The resultant stream water quality would increase slightly in EC and more significantly in SAR from existing conditions. The resultant mixed stream water can be compared with the available surface water criteria:

- MRPL: The water quality in the Powder River at Locate, Montana, currently exceeds the MRPL for EC and SAR; thus, any additional discharge that would reach the main stem would likely cause further degradation in terms of suitability for irrigation if the states and EPA conclude that the MRPL is protective of irrigation uses.
- LRPL: Under modeled conditions, both constituents would be less than the LRPL, with the exception of the SAR during minimum mean monthly flow.
- Ayers and Westcot diagram: Irrigation with the resultant quality of the mixed water indicates a reduction in infiltration is not likely during mean monthly or 7Q10 flow conditions. During the low monthly flow, essentially 100 of the CBM discharge could occur without causing potential effects to infiltration.

Modeling indicates that the suitability of the Tongue River for irrigation may be compromised by the surface discharge of CBM produced water during maximum CBM development in both states. Still, existing interstate agreements have been developed to minimize impacts to water quality until such time that protective standards are put in place and the assimilative capacity can be equitably divided among the states and tribes. Surface discharge to the Tongue River from CBM development in both states currently

Table 6-1
Cumulative Surface Water Impact Analysis

Alternative	Station	Most Restrictive Proposed Upper Limit		Least Restrictive Proposed Upper Limit		Existing Stream Water Quality Minimum Mean Monthly Flow			Resulting Stream Water Quality at Minimum Mean Monthly Flow			Existing Stream Water Quality 7Q10 Flow			Resulting Stream Water Quality 7Q10 Flow		
		SAR	EC (μS/cm)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)	Flow (cfs)	SAR	EC (μS/cm)
Wyoming 2A and Montana E	Tongue River below Brandenburg Bridge near Ashland, MT	0.5	500	10	2500	207	1.36	1016	214	2.5	1058	70	1.82	1281	76	4.95-5.31	1368-1377
	Powder River at Locate, MT	2.0	1000	10	3200	143	4.6	2287	250	13.1	2361	1.6	6.87	3313	109	21.6-24.3	2384-2473

Notes:
SAR = Sodium adsorption ratio
EC = Electrical conductivity
cfs = Cubic feet per second
μS/cm = Microsiemens per centimeter
7Q10 = The minimum flow averaged over 7 consecutive days that is expected to occur on average, once in any 10-year period.

is controlled by the two state DEQs, which have agreed to an interim "no new discharge" policy that would not authorize untreated surface discharge of CBM waters to the Tongue River unless the quality of the discharged water was at or near the existing water quality in the Tongue River.

Cumulative effects to the suitability for irrigation of the Powder River would be minimized through the interim MOC the two DEQs have entered. The MOC was developed to ensure that designated uses downstream in Montana would be protected while CBM development in both states continued. As the states develop a better understanding of the effects of CBM discharges through the enhanced monitoring required by the MOC, they can adjust the permitting approaches to allow more or less discharges to the Powder River drainage. Thus, water quality standards can be met, and downstream uses can be maintained.

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APPENDIX A

Numeric Standards Proposed for the Tongue, Powder, and Little Powder River Basins, and Adopted for the Cheyenne and Belle Fourche River Basins

Appendix A
Specific Electrical Conductivity (EC as uS/cm) and Sodium Adsorption Ratio (SAR) Values Proposed for the Tongue, Powder, and Little Powder River Basins and Adopted for the Cheyenne and Belle Fourche River Basins

Wyoming currently implements its narrative water quality standard through its NPDES permitting program. Implementation is on a watershed basis, with DEQ setting permit limits that are determined to be protective of downstream irrigated agriculture. Wyoming, therefore, does not have specific numerical standards for SAR and EC at this time. Nevertheless, numerical standards of downstream jurisdictions apply and may have an affect on discharges in Wyoming. The SAR and EC values in this table are: 1) those adopted by the Northern Cheyenne Tribe and the specific values proposed by the parties to the Montana water quality standards process now underway; and 2) those adopted, as statewide standards, by South Dakota. None of the numerical values applicable to the Tongue, Powder, and Little Powder in Montana has final Clean Water Act (CWA) status, and it is not certain, at this point, what the final CWA values applicable to these Rivers will be. Nevertheless, these SAR and EC values were developed with assistance from advisors with expertise in the area of salinity and sodicity effects on irrigated agriculture. Therefore, it would not be unreasonable to view these values as providing a fair estimate of the range of SAR and EC values which may eventually be judged as providing an appropriate level of protection for irrigated agriculture in these basins. The numerical standards applicable to the Cheyenne and Belle Fouche Rivers in South Dakota are final standards with CWA status. The values are presented here simply to provide the reader with easy link to the standards development process now underway in Montana and the South Dakota water quality standards.

Specific EC and SAR Values Under Consideration in the Montana Water Quality Standards Process

Montana DEQ Option 1

Watershed	**Irrigation Season (4/1 - 10/31)**	**Non-Irrigation Season (11/1-3/31)**	**Criteria Applicable All Year to All Waters**		**Notes**
	EC (max)	EC (max)	SAR (max)	SAR (abs. max)	SAR(max) is the SAR calculated using the ambient EC, for a specific sampling event, in the equation. The calculated SAR is a maximum. SAR(abs. max) is a maximum, not to be exceeded, value that applies to all waters at all times and is based on protecting against the rain-on-sodic-soil event. SAR(abs. max) is 0.5 where EC is less than 350. Although specific numeric standards for EC and SAR (as prescribed in this table) have been proposed, Montana's Option 1 proposal includes a range of potential values that could be considered for adoption by the Board. For SAR, the range is 1 - 10. For EC, the range is 350 - 2500.
Tongue River	1000	2000	EC x 0.0071 - 2.475	5.0	
Tributaries to the Tongue River	500				
Powder River	1900				
Tributaries to the Powder River	500				
Little Powder River	1900				
Tributaries to the Little Powder River	500				

Montana DEQ Option 2

This option is the same as option 1, except for the Tongue River. For the Tongue River, the standards progressively become more stringent from downstream to upstream. This is to protect assimilative capacity in the Montana portion of the River, ensuring the desired level of water quality is attained at the mouth of the River while allowing for development in the upper section of the basin.

Watershed	**Irrigation Season (4/1 - 10/31)**	**Non-Irrigation Season (11/1-3/31)**	**Criteria Applicable All Year to All Waters**		**Notes**
	EC (max)	EC (max)	SAR (max)	SAR (abs. max)	SAR(max) is the SAR calculated using the ambient EC, for a specific sampling event, in the equation. The calculated SAR is a maximum. SAR(abs. max) is a maximum, not to be exceeded, value that applies to all waters at all times and is based on protecting against the rain-on-sodic-soil event. SAR(abs. max) is 0.5 where EC is less than 350. Although specific numeric standards for EC and SAR (as presented in this table) have been proposed, Montana's Option 2 proposal includes a range of potential values that could be considered for adoption by the Board. For SAR, the range is 1 - 10. For EC, the range is 350 - 2500.
Tongue River (Yellowstone R. - N. Cheyenne, northern	1000	2000	EC x 0.0071 - 2.475	5.0	
Tongue River (N. Cheyenne, northern boundary - southern boundary)	900				
Tongue River (N. Cheyenne, southern boundary - reservoir inlet)	700				
Tongue River (reservoir inlet Wy border)	600				
Tributaries to the Tongue River	500				
Powder River	1900				
Tributaries to Powder River	500				
Little Powder River	1900				
Tributaries to the Little Powder River	500				

Petitioners[1] Proposal

This proposal is similar to DEQ's option 2 in that there are multiple standards for each river and the standards become progressively more stringent from downstream to upstream. This proposal also includes multiple irrigation periods at certain locations.

River Segments and Compliance Locations	EC (max)	SAR (max)	Notes
Tongue River - Wyoming state line	600	0.5	Applicable dates: all year
Tongue River - Reservoir	800	1.0	Applicable dates: all year
Tongue River - at conf. w. Yellowstone R.	1000	1.6	Applicable dates: 4/1 - 10/31
Tongue River - at conf. w. Yellowstone R.	1200	2.5	Applicable dates: 11/1 - 3/31
Powder River - Moorhead	1400	4.0	Applicable dates: 4/15 - 7/15
Powder River - Moorhead	2200	5.0	Applicable dates: 7/16 - 9/1
Powder River - Moorhead	3000	6.0	Applicable dates: 9/2 - 4/14
Powder River - at conf. w. Yellowstone R.	1600	4.0	Applicable dates: 4/15 - 7/15
Powder River - at conf. w. Yellowstone R.	2400	5.0	Applicable dates: 7/16 - 9/1
Powder River - at conf. w. Yellowstone R.	3200	6.0	Applicable dates: 9/2 - 4/14
Little Powder - Biddle	2000	5.0	Applicable dates: 4/15 - 7/15
Little Powder - Biddle	2400	6.0	Applicable dates: 7/16 - 9/1
Little Powder - Biddle	3000	8.0	Applicable dates: 9/2 - 4/14

[1] "Petitioners" include -Tongue River Water Users, T&Y Irrigation District, Buffalo Rapids Irrigation Project, and Northern Plains Resource Council.

WQS for Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR) Adopted by the Northern Cheyenne Tribe

The Northern Cheyenne Tribe's EC and SAR numerical standards were adopted by the Tribal Council on May 28, 2002. The numerical standards apply to the Tongue River and tributaries within the boundaries of the Reservation.

Tongue River (within the Reservation Boundaries)	**Irrigation Season (4/1 - 11/15)**	**Criteria Applicable All Year**		**Notes**
	EC (30-day ave.)	EC (inst. max.)	SAR (inst. max.)	The Tribe has also adopted indicator values for total dissolved solids (TDS) that will be used to monitor conditions and trends of these waters.
Southern Boundary	1000	2000	2.0	
Northern Boundary	1500	2000	3.0	
Tributaries	1500	2000	3.0	

WQS for Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR) Adopted by South Dakota

Watershed	**Criteria Applicable All Year**			**Notes**
Belle Fourche and Cheyenne Rivers and tributaries	EC (30-day ave.)	EC (daily max)	SAR (daily max)	
	≤ 2500	≤ 4375	≤ 10	

Wyoming Narrative WQS Concerning Agricultural Water Supply

Section 20 of Wyoming's Chapter 1 Rules and Regulations incorporates a narrative water quality standard, which specifies that all surface waters with potential for use as an agricultural water supply shall be maintained at a quality which supports the use, and any degradation shall not cause a measurable decrease in crop or livestock production. Unless otherwise demonstrated, all Wyoming surface waters are assumed to have the natural water quality potential for use as an agricultural water supply.

APPENDIX B

Analysis of SAR Mixing

APPENDIX B
ANALYSIS OF SAR MIXING

This appendix addresses the estimation of sodium adsorption ratio (SAR) in rivers of the Powder River Basin after mixing with discharge of coal bed methane (CBM) produced water. The following sections provide (1) a summary of the analysis, (2) the definition of SAR, (3) an explanation of ideal mixing in a river, (4) an evaluation of the ambient SAR at the three stateline river stations (Powder River at Moorhead, Little Powder River above Dry Creek, and Tongue River at Stateline) and the SAR of CBM produced-water discharge, and (5) an analysis of mixing approaches for estimating SAR in the river after discharge of CBM produced water.

A.1. Summary and Conclusions

This analysis concludes that a simple mixing approach to estimating SAR in a river after mixing with CBM discharge provides an acceptable, reasonably conservative estimate of the mixed SAR. In this approach, SAR is treated as a constituent of water and mixed using a simple flow-weighted mass balance equation. The mixed SAR calculated using this approach over-predicts SAR by a consistently conservative average factor of about 1.6 for the Powder River Basin. This error is relatively insignificant when compared to the variability in the other parameters used in modeling impacts of CBM discharge on water quality . Therefore, this method of calculating SAR is appropriate for use in this EIS.

When site-specific, synoptic water quality data are available for a particular project, or when determining TMDLs, the resultant mixed water quality should be determined by mixing the individual constituents in the SAR formula –Ca, Mg, and Na.

A.2. Definition of SAR

Sodium adsorption ratio (SAR) is used as an index of the potential for irrigation water to lessen the permeability of a soil subject to swelling if sodium exchanges for calcium and magnesium in soil particles. SAR is calculated as:

$$SAR = \frac{[Na]}{\sqrt{\frac{[Ca]+[Mg]}{2}}} \qquad [1]$$

where [Na], [Ca], and [Mg] represent the concentrations of sodium, calcium, and magnesium, respectively, expressed in milliequivalents per liter (meq/L) (USDA, 1954).

A.3. Ideal Mixing

Estimation of SAR in a river after mixing with CBM discharge ideally is calculated using a flow-weighted mass balance model to estimate mixed concentrations of the individual constituents—Ca, Mg, and Na. If complete mixing is assumed, the mixed concentration of each constituent can be calculated as (US EPA, 1995):

$$C_{mix} = \frac{Q_{river}C_{river} + Q_{discharge}C_{discharge}}{Q_{river} + Q_{discharge}} \qquad [2]$$

where

C_{mix}	=	concentration of constituent in the mixed zone,
Q_{river}	=	upstream (ambient) flow rate,
$Q_{discharge}$	=	discharge flow rate,
C_{river}	=	upstream (ambient) constituent concentration,
$C_{discharge}$	=	discharge constituent concentration,

This equation applies to any chemical constituent in the river and discharge that mixes conservatively (i.e., does not react upon mixing). Combining equations [1] and [2] yields the following equation for SAR mixing:

$$SAR_{mix} = \frac{\left\{\dfrac{(Q_{river} \times [Na]_{river}) + (Q_{CBM} \times [Na]_{CBM})}{(Q_{river} + Q_{CBM})}\right\}}{\sqrt{\dfrac{\left\{\dfrac{(Q_{river} \times Ca_{river}) + (Q_{CBM} \times Ca_{CBM})}{(Q_{river} + Q_{CBM})} + \dfrac{(Q_{river} \times Mg_{river}) + (Q_{CBM} \times Mg_{CBM})}{(Q_{river} + Q_{CBM})}\right\}}{2}}} \qquad [3]$$

In order to ensure that a representative mixed value is calculated, the upstream river and discharge samples should have been collected synoptically (concurrent sampling of the water in each inflow that will ultimately mix at the confluence of the two flows). If synoptic data are not available, application of equation [3] implies estimating representative values of [Na], [Ca], and [Mg] for the upstream river water and the CBM discharge.

A.4. Ambient River SAR and CBM Produced WaterSAR

This section analyzes different methods of calculating measures of central tendency (mean or median) to represent ambient river SAR and CBM produced water SAR. The mean and median SAR values calculated from individual samples are compared to the SAR values estimated from the mean and median values of Ca, Mg, and Na concentrations in individual samples. Because of the square root in the SAR formula, calculation of a mean SAR from sample SARs is not strictly correct. It is nevertheless investigated in this analysis in order to evaluate the use of a simplified mixing model for SAR when synoptic water quality data are not available.

The data evaluated include data sets from three river stations (Powder River at Moorhead, Little Powder River above Dry Creek, and Tongue River at Stateline) as well as water quality data compiled for CBM produced-water discharge. The river data was obtained from the USGS NWIS database. The CBM data was obtained from a USGS study of the Powder River Basin (Rice et al., in press) and from data submitted to EPA by Fidelity for a UIC permit for the CX Ranch development.

Table A-1 and Figure A-1 compare the mean of sample SAR values to the SAR value estimated from mean values of Ca, Mg, and Na. As is shown in Table A-1 and Figure A-1, either way of estimating a representative SAR for the data yields equivalent results for the river station data. However, for the CBM data sets, estimating SAR from the mean values of Ca, Mg, and Na results in a significant under-prediction of the mean SAR value and, consequently from a regulatory standpoint, results in a less conservative and less acceptable estimate of SAR.

Table A-1
Comparison of (1) Mean Values of Sample SARs and
(2) SARs Estimated from Mean Values of Sample Ca, Mg, and Na Concentrations

	(1)				(2)		
	Mean SAR	Mean Ca (mg/L)	Mean Mg (mg/L)	Mean Na (mg/L)	CaMgNa SAR	Ratio (1)/(2)	Ratio (2)/(1)
Powder River at Moorhead, MT	**4.94**	119	59	262	**4.91**	1.01	0.99
Little Powder River above Dry Creek, WY	**6.24**	141	96	404	**6.43**	0.97	1.03
Tongue River at State line near Decker, MT	**0.68**	55	33	27	**0.71**	0.95	1.05
Powder River Basin CBM Discharge	**20.7**	29	14	391	**15.0**	1.38	0.72
CX Ranch CBM Discharge	**44.7**	11	11	553	**28.5**	1.57	0.64
Fort Union Coal	**14.5**	161	192	401	**5.1**	2.86	0.35

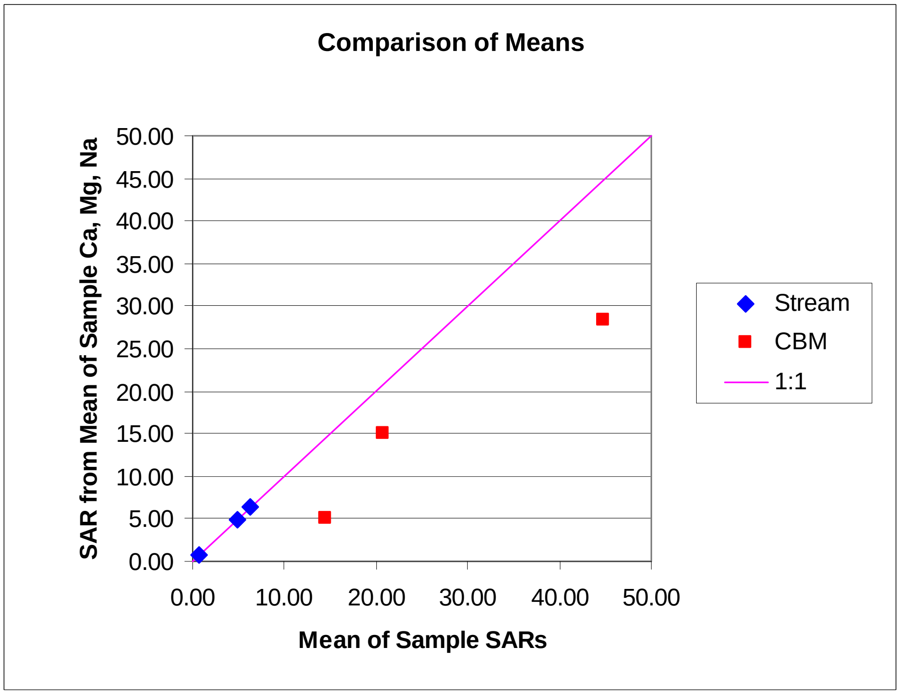

Figure A-1. Comparison of mean values of individual sample SARs and SARs estimated from mean values of sample Ca, Mg, and Na concentrations.

Similar information is presented in Table A-2 and Figure A-2 using median rather than mean values. For data from the river stations, either way of estimating a representative SAR yields equivalent results. This is the same result as was found when using mean values. For the CBM data sets, however, SAR estimated from the median values of Ca, Mg, and Na appears to over-predict SAR. The over-prediction in these examples is not as large as the under-prediction that results from using mean values as shown in Table A-1 and Figure A-1. From a regulatory standpoint, reasonable over-prediction is acceptable and, consequently, either method of calculating SAR using median values yields an acceptable estimate.

Table A-2
Comparison of (1) Median Values of Sample SARs and
(2) SARs Estimated from Median Values of Sample Ca, Mg, and Na Concentrations

	(1) Median SAR	Median Ca (mg/L)	Median Mg (mg/L)	Median Na (mg/L)	(2) CaMgNa SAR	Ratio (1)/(2)	Ratio (2)/(1)
Powder River at Moorhead, MT	**4.94**	120	56	267	**5.05**	0.98	1.02
Little Powder River above Dry Creek, WY	**6.61**	150	108	438	**6.66**	0.99	1.01
Tongue River at State line near Decker, MT	**0.66**	59	36	26	**0.66**	1.00	1.00
Powder River Basin CBM Discharge	**11.5**	26	13	353	**14.1**	0.81	1.23
CX Ranch CBM Discharge	**47.5**	6	2	549	**47.9**	0.99	1.01
Fort Union Coal	**4.6**	109	102	329	**5.4**	0.85	1.18

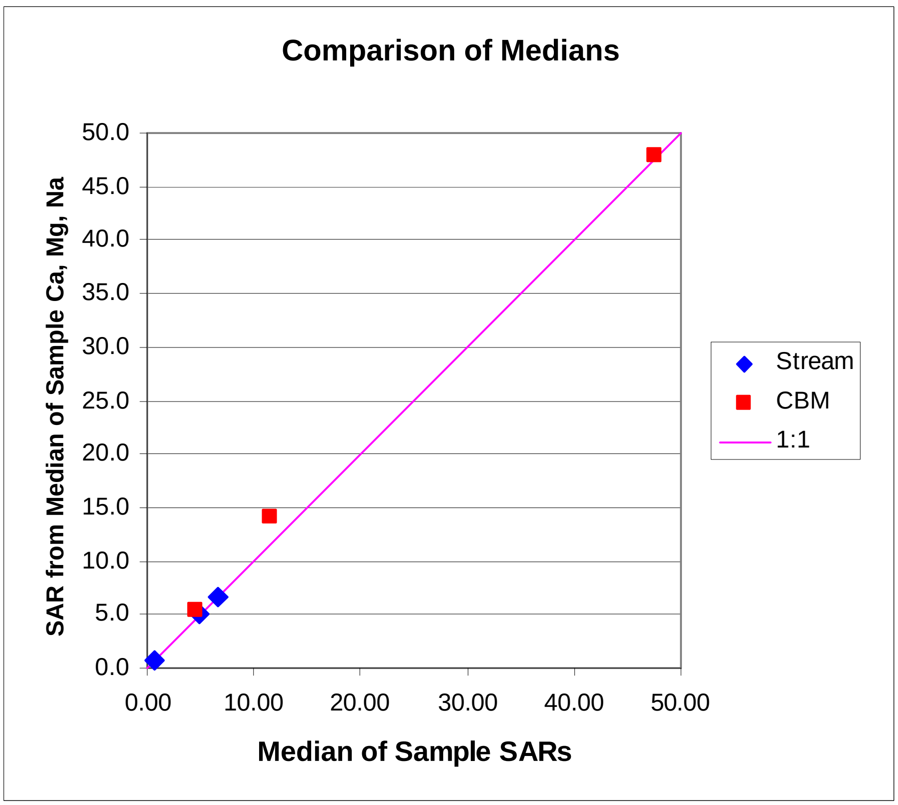

Figure A-2. Comparison of median values of sample SARs and SARs calculated from median values of sample Ca, Mg, and Na concentrations.

A. 5. SAR Mixing

As described above, estimation of SAR in a river after mixing with CBM discharge ideally is calculated using synoptic data and equation [3]. However, because synoptic data generally are not available for the streams or CBM discharges evaluated in the EIS, this section evaluates using the simple flow-weighted mass balance model, shown in equation [2], to estimate SAR after mixing. The corresponding simple mixing model for SAR is:

$$SAR_{simple\ mix} = \frac{(Q_{River} \times SAR_{River}) + (Q_{CBM} \times SAR_{CBM})}{(Q_{River} + Q_{CBM})} \qquad [4]$$

Two approaches are used to evaluate the use of equation [4] in place of equation [3]. One approach considers fractional mixing of stream water with CBM discharge using representative mean or median values of SAR, Ca, Mg, and Na for both the stream and CBM discharge. The other approach mixes CBM discharge characterized by representative mean values for water quality parameters with individual samples from each of the stateline stations.

A.5.1. Fractional Mixing Analysis

The fractional mixing analysis is illustrated in Figure A-3 using mean values of SAR, Ca, Mg, and Na from the Powder River at Moorhead station and CBM discharge in the Power River watershed. The figure compares the simple mix SAR values estimated using equation [4] to SAR values estimated using equation [3]. As shown, the simple SAR mixing approach overestimates SAR in the Powder River station at Moorhead by a factor ranging up to 1.33 at the reasonably foreseeable development (RFD) CBM discharge.

Table A-3 presents a summary of the results of the fractional mixing analysis for each of the stateline stations. This table shows that the simple mix approach—equation [4]—over-predicts SAR by a factor of at most 1.4 at the Powder River and Little Powder River stateline stations. At the Tongue River stateline station, the simple mix approach overestimates SAR by a factor of at most 1.6 using mean values and 2.7 using median values.

The over-prediction in SAR that results from using the simple mass balance approach is small when compared to the other uncertainties inherent in the impact analysis modeling. Consequently, this approach is considered appropriate for purposes of this EIS, as it yields a reasonably conservative estimate of SAR.

Powder River at Moorhead: Mean Values					
Flow	Sample SAR	Ca	Mg	Na	CaMgNa SAR
388	4.94	118	58	261	4.91

CBM Discharge: Mean Values					
Flow	Sample SAR	Ca	Mg	Na	CaMgNa SAR
206	**20.7**	29	14	540	**20.7**

Mix						
Frac	Simple SAR Mix (1)	Ca Mix	Mg Mix	Na Mix	CaMgNa Mix SAR (2)	Ratio (1):(2)
0	4.94	118	58	261	4.91	1.01
0.05	5.35	116	57	268	5.10	1.05
0.1	5.73	114	56	275	5.28	1.09
0.15	6.10	112	55	282	5.45	1.12
0.2	6.45	110	54	288	5.62	1.15
0.25	6.79	108	53	294	5.79	1.17
0.3	7.10	106	52	299	5.95	1.19
0.35	7.41	104	51	305	6.10	1.21
0.4	7.70	103	51	310	6.26	1.23
0.45	7.98	101	50	315	6.41	1.25
0.5	8.24	100	49	320	6.55	1.26
0.55	8.50	98	48	324	6.69	1.27
0.6	8.75	97	48	328	6.83	1.28
0.65	8.98	95	47	333	6.97	1.29
0.7	9.21	94	46	337	7.10	1.30
0.75	9.43	93	46	340	7.23	1.30
0.8	9.64	92	45	344	7.35	1.31
0.85	9.84	91	45	348	7.48	1.32
0.9	10.03	89	44	351	7.60	1.32
0.95	10.22	88	43	354	7.72	1.32
1	10.41	87	43	358	7.83	1.33

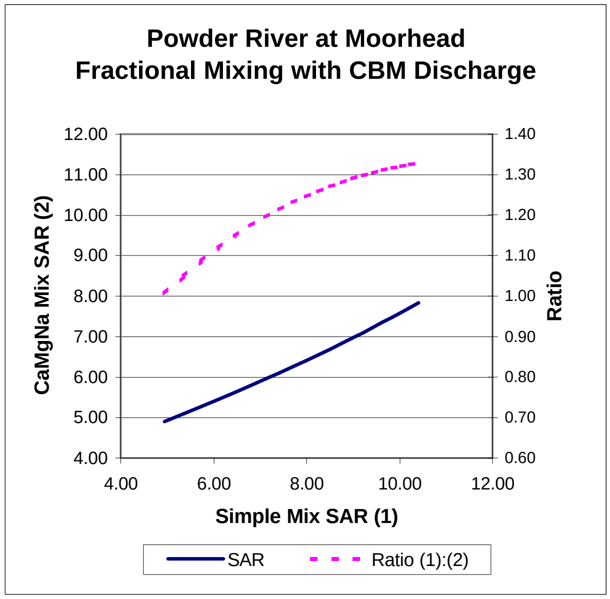

Figure A-3. Fractional mixing of stream water and CBM discharge. Comparison of SAR values calculated using (1) simple mixing as in equation [4] and (2) flow-weighted mixing of Ca, Mg, and Na as in equation [3].

Table A-3
Summary of Fractional Mixing Results. Comparison of SAR values calculated using simple mixing versus flow-weighted mixing of Ca, Mg, and Na.

Station	Statistic Used to Represent Water Quality	Average Ratio of Simple SAR Mix to Ca, Mg, Na Mixed SAR	Ratio of Simple SAR Mix to Ca, Mg, Na Mixed SAR at RFD CBM Discharge
Tongue River	Mean	1.40	1.60
Tongue River	Median	2.33	2.67
Powder River	Mean	1.23	1.33
Powder River	Median	1.12	1.20
Little Powder River	Mean	1.24	1.36
Little Powder River	Median	1.17	1.12

A.5.2. Distribution Mixing Analysis

Results similar to those obtained in the fractional mixing analysis are obtained by mixing individual samples of river water at the stateline stations (USGS data) with CBM discharge (mean values). The results are illustrated in Figures A-4 and A-5. These figures both indicate that the simple mix approach—equation [4]—over-predicts SAR by a factor of approximately 1.6 at both the Tongue River and Powder River stateline stations. As above, this over-prediction of SAR represents a conservative, yet reasonable estimate of SAR and, consequently, the simple mixing approach is the approach used in the analysis of impacts for the EIS.

References:

U.S. Dept. of Agriculture (USDA), 1954, *Agriculture Handbook 60*. www.ussl.ars.usda.gov/hb60/hb60requ.htm

U.S. EPA Region VIII, 1995, *Mixing Zones and Dilution Policy*.

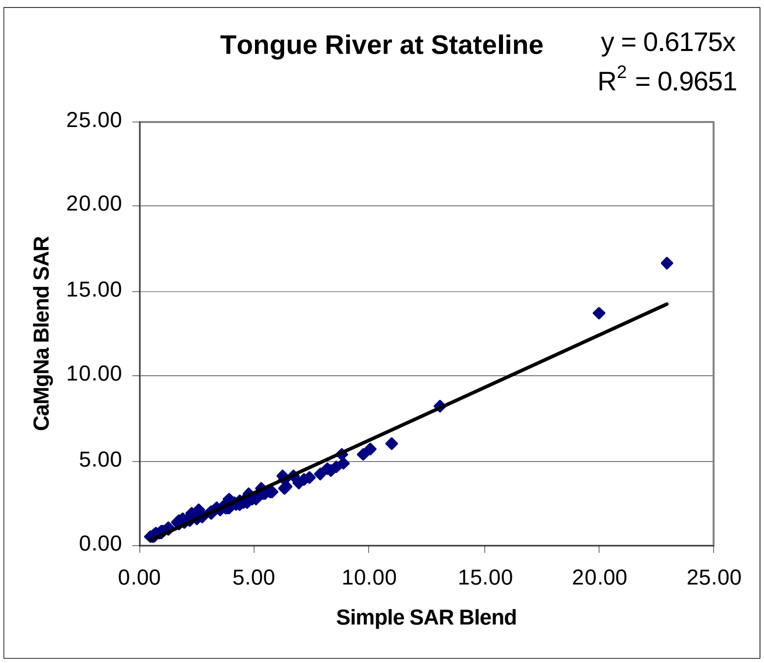

Figure 4. Tongue River at Stateline (USGS data) mixed with CX Ranch CBM discharge (mean values). Comparison of SAR values calculated using simple mixing as in equation [4] and flow-weighted mixing of Ca, Mg, and Na as in equation [3].

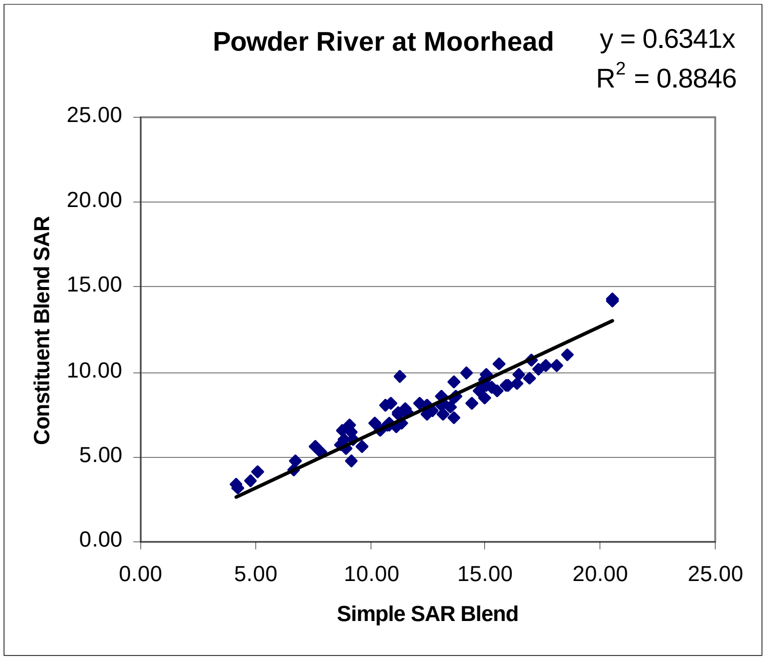

Figure 5. Powder River at Moorhead (USGS data) mixed with Powder River Basin CBM discharge (mean values). Comparison of SAR values calculated using simple mixing as in equation [4] and flow-weighted mixing of Ca, Mg, and Na as in equation [3].

APPENDIX C

Existing Stream Flow and Water Quality Parameters at Selected Gauging Stations within the PRB

Appendix C
Monthly Stream Flow and Water Quality Parameters at Selected Gaging Stations within the PRB

Sub-watershed	Stream Guage Location	Parameter	7Q10	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Wyoming Streams															
Upper Belle Fourche	Belle Fourche River below Moorcroft, WY (06426500)	SAR	--	6.29	4.08	3.64	4.34	3.81	3.98	3.10	5.06	5.76	5.75	7.02	6.77
		EC	--	2887	1907	1564	1722	1532	1821	1182	1955	2231	2346	2877	2755
		Flow	0	3.56	18.2	59.3	27.2	68.1	62.1	19.6	10.4	5.31	5.72	2.32	2.31
Antelope Creek	Antelope Creek near Teckla, WY (06364700)	SAR	--	2.74	2.71	2.52	2.77	2.82	2.80	2.48	2.47	2.52	2.60	2.74	2.79
		EC	--	2335	2251	1782	1949	1800	2005	1661	1684	2214	2354	2460	2372
		Flow	nc	0.26	0.46	11.0	7.94	58.8	7.77	23.5	6.42	0.33	0.16	0.20	0.30
Upper Cheyenne	Cheyenne River near Riverview, WY (06386500)	SAR	--	8.58	8.01	8.66	7.87	6.88	5.93	5.69	4.82	5.63	6.46	7.22	7.39
		EC	--	4229	3911	4127	3630	3155	2895	2250	1972	2271	2916	3565	3405
		Flow	nc	2.49	0.98	0.38	3.46	16.2	16.8	33.8	188.0	231.4	121.7	52.0	29.3
Upper Powder River	Powder River near Arvada, WY (06317000)	SAR	--	6.40	6.12	5.28	5.84	4.92	4.76	6.79	6.97	7.83	6.71	6.42	6.61
		EC	--	2482	2366	2051	2213	1803	1797	2716	2992	3400	2537	2650	2906
		Flow	0	90.8	169.7	393.9	357.2	737.2	752.2	261.0	96.5	75.4	137.5	129.0	100.5
Clear Creek	Clear Creek near Arvada, WY (06324000)	SAR	3.96	1.29	1.33	1.26	1.28	1.36	1.07	1.38	1.46	1.52	1.32	1.24	1.36
		EC	3879	1144	1218	1075	1106	1103	883	1177	1276	1458	1176	1173	1237
		Flow	0.1	72.1	83.8	160.6	171.2	396.8	658.6	175.5	62.3	77.1	94.3	106.4	88.0
Crazy Woman Creek	Crazy Woman Creek near Arvada, WY (06316400)	SAR	--	1.86	1.76	1.76	2.02	1.67	1.29	1.77	1.98	2.26	1.92	1.86	1.88
		EC	--	1619	1488	1395	1550	1294	1066	1476	1739	1937	1720	1590	1635
		Flow	0	14.4	18.5	47.2	33.3	110.9	217.0	59.9	17.1	13.9	17.4	19.5	17.6
Salt Creek	Salt Creek near Sussex, WY (06313400)	SAR	25.1	23.7	21.4	17.9	22.1	18.9	22.6	25.9	24.9	20.8	24.8	24.3	26.1
		EC	6741	5668	5317	4877	5558	5204	5043	5436	5656	5248	5612	5980	5750
		Flow	8.35	29.0	44.3	66.6	48.7	84.7	66.8	48.1	30.5	30.1	35.4	29.5	26.8
Wyoming/Montana Streams															
Upper Tongue River	Tongue River at Stateline near Decker, MT (06306300)	SAR	1.29	0.76	0.70	0.74	0.71	0.38	0.36	0.57	0.86	0.84	0.68	0.68	0.72
		EC	1179	701	651	658	615	318	318	474	731	704	647	633	688
		Flow	43.2	179.5	232.3	308.0	360.4	1157.4	1669.8	470.0	178.3	219.7	256.5	226.1	180.8
Middle Powder	Powder River near Moorhead, MT (06324500)	SAR	6.15	5.03	4.61	5.39	5.43	4.82	3.92	4.20	4.70	4.62	5.60	4.79	4.76
		EC	4400	2138	1864	1929	2134	1669	1421	1761	2196	2154	2307	1974	2294
		Flow	0.26	153.0	288.6	618.1	510.4	1069.1	1384.3	472.5	174.2	144.6	228.8	226.3	159.6
Little Powder River	Little Powder River near Weston, WY (06324970)	SAR	--	6.33	5.57	4.44	5.55	4.81	5.29	5.29	6.57	6.44	5.73	6.70	6.94
		EC	--	2953	2477	1785	2457	2013	2333	2174	2860	2810	2289	3044	3300
		Flow	0	8.3	38.8	62.0	24.3	59.9	29.3	11.4	5.7	4.1	11.7	4.0	2.6
Montana Streams															
Upper Tongue River	Tongue River at Birney Day School, near Birney, MT (06307616)	SAR	1.60	1.03	1.12	1.09	1.11	0.81	0.59	0.61	0.71	0.94	1.02	0.99	1.09
		EC	1159	851	924	821	783	650	367	366	472	623	684	710	863
		Flow	45	183	202	232	284	677	1158	570	410	329	252	224	183
Lower Tongue River	Tongue River below Brandenberg Bridge near Ashland, MT (06307830)	SAR	1.82	1.38	1.35	1.40	1.53	1.17	0.71	0.76	0.79	1.10	1.25	1.45	1.36
		EC	1281	975	976	878	965	793	392	461	591	734	831	949	1016
		Flow	70	235	248	321	360	941	1633	746	474	339	289	230	207
Lower Powder River	Powder River at Locate, MT (06326500)	SAR	6.87	4.61	4.11	3.41	4.73	4.01	3.25	4.14	4.53	5.34	5.05	4.41	5.00
		EC	3313	2287	1720	1437	1944	1442	1432	1713	2251	2316	2123	2305	2619
		Flow	1.6	143	441	1266	739	1144	1629	592	219	171	249	213	149
Mizpah Creek	Mizpah Creek at Mizpah, MT (06326300)	SAR	--	18.0	9.5	8.2	12.5	13.7	11.5	12.0	18.7	15.0	15.8	15.7	16.6
		EC	--	2226	1126	1131	2065	2065	2082	2172	1915	1010	2010	2579	3503
		Flow	0	1.9	29.4	60.1	17.3	39.2	19.4	5.9	18.7	15.9	4.9	0.3	0.3

Appendix C

Monthly Stream Flow and Water Quality Parameters at Selected Gaging Stations within the PRB

Sub-watershed	Stream Guage Location	Parameter	7Q10	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Little Bighorn River	Little Bighorn River at Stateline near Wyola, MT (06289000)	SAR	0.8	0.55	0.68	0.88	0.94	0.52	0.25	0.38	0.52	0.57	0.52	0.56	0.53
		EC	629	552	577	651	648	484	393	470	515	553	547	546	548
		Flow	47	113	181	191	298	618	798	304	128	133	132	127	110
	Little Bighorn River near Hardin, MT (06294000)	SAR	1.60	1.06	1.23	2.00	2.06	1.39	0.59	0.89	0.99	1.12	0.99	0.98	1.09
		EC	830	754	795	826	956	691	496	637	768	705	691	715	790
		Flow	21	144	207	321	322	632	851	273	123	131	158	156	138
Bighorn River	Bighorn River at Bighorn, MT (06294700)	SAR	2.80	2.08	2.03	2.09	2.33	2.16	2.09	2.14	2.41	2.31	2.24	2.18	2.12
		EC	989	952	950	978	1068	958	864	938	841	939	987	1024	1000
		Flow	870	1523	1676	3423	3499	6763	16130	10180	4282	2869	2786	2278	1881
Rosebud Creek	Rosebud Creek at Reservation boundary, near Kirby, MT (06295113)	SAR	1.16	0.63	0.60	0.53	0.54	0.61	0.62	0.68	0.74	0.77	0.72	0.72	0.65
		EC	1123	906	965	828	912	898	866	899	934	1016	1056	1031	1042
		Flow	0.1	3.6	6.8	14.6	15.7	13.1	9.2	4.0	1.8	1.8	3.0	3.5	3.5
	Rosebud Creek at mouth, near Rosebud, MT (06296003)	SAR	--	2.18	1.62	1.76	2.85	3.22	2.79	4.26	4.84	4.29	3.80	3.00	2.36
		EC	--	1827	1532	1071	1647	1588	1566	1897	1780	1983	1922	2038	2294
		Flow	0	20.0	39.9	74.9	44.9	63.1	42.4	18.7	8.4	8.8	8.7	9.8	10.5
Lower Yellowstone-Sunday	Yellowstone River at Forsyth, MT (06295000)	SAR	--	1.99	1.59	1.65	1.64	1.75	1.72	na	na	na	na	na	na
		EC	--	745	587	659	701	692	576	642	585	555	492	484	597
		Flow	nc	5820	6245	7219	7735	17350	30730	18800	8165	6937	7338	6986	6210
Lower Yellowstone	Yellowstone River near Sidney, MT (06329500)	SAR	2.52	2.00	1.97	2.00	2.11	1.57	1.21	1.42	1.92	2.14	2.03	2.00	2.00
		EC	809	870	807	826	906	574	424	532	632	750	780	832	884
		Flow	2240	5764	6922	11080	10430	18490	39260	22360	8852	7234	8371	7401	5999

Notes:

na = not available

nc = not calculated due to insufficient record

APPENDIX D

Coal Bed Methane Parameters Used to Evaluate Potential Impacts to Surface Water Quality

Appendix D
Coal Bed Methane Parameters Used to Evaluate Potential Impacts to Surface Water Quality

			Wyoming Input						Montana Input					
Sub-watershed	Stream Guage Location	Alternative	WY Number of CBM Wells	Average CBM Well Discharge Rate (gpm)	Managed Water Loss (percent)	Channel Loss (percent)	CBM Produced Water EC (uS/cm)	CBM Produced Water SAR	MT Number of CBM Wells	Average CBM Well Discharge Rate (gpm)	Managed Water Loss (percent)	Channel Loss (percent)	CBM Produced Water EC (uS/cm)	CBM Produced Water SAR
Wyoming Streams														
Upper Belle Fourche	Belle Fourche River below Moorcroft, WY	1			49.0									
		2A	7,630	7.0	35.5	20	970	8.2	NA	NA	NA	NA	NA	NA
		2B			35.5									
		3	6,160	6.2	49.0									
Antelope Creek	Antelope Creek near Teckla, WY	1			39.8									
		2A	925	11.9	35.5	20	905	7.1	NA	NA	NA	NA	NA	NA
		2B			36.3									
		3	561	11.9	39.8									
Upper Cheyenne	Cheyenne River near Riverview, WY	1			39.8									
		2A	546	9.6	35.5	20	599	6.4	NA	NA	NA	NA	NA	NA
		2B			36.3									
		3	469	9.1	39.8									
Upper Powder River	Powder River near Arvada, WY	1			22.8									
		2A	15,822	6.2	61.0	20	2163	19.5	NA	NA	NA	NA	NA	NA
		2B			64.0									
		3	5,322	6.2	22.8									
Clear Creek	Clear Creek near Arvada, WY	1			59.0									
		2A	2,257	6.2	84.5	20	3022	29.2	NA	NA	NA	NA	NA	NA
		2B			87.5									
		3	1,705	6.2	59.0									
Crazy Woman Creek	Crazy Woman Creek near Arvada, WY	1			29.3									
		2A	1,853	6.2	84.5	20	3129	24.8	NA	NA	NA	NA	NA	NA
		2B			88.3									
		3	606	6.2	29.3									
Salt Creek	Salt Creek near Sussex, WY	1			39.8									
		2A	37	6.2	89.5	20	1415	9.7	NA	NA	NA	NA	NA	NA
		2B			92.5									
		3	19	6.2	39.8									
Wyoming/Montana Streams														
Upper Tongue River	Tongue River at Stateline near Decker, MT	1			58.3									
		2A	1,948	6.2	85.3	20	2406	38.7	530	6.2	71.0	20	2406	47
		2B			88.3									
		3	1,786	6.2	58.3									
Middle Powder	Powder River near Moorhead, MT	1			28.1						100			
		2A	21,047	6.2	65.9	20	2370	21.8	568	6.2	0	20	3042	41.9
		2B			68.9						0			
		3	8,469	6.2	28.1						0			
Little Powder River	Little Powder River near Weston, WY	1			33.5									
		2A	2,543	6.2	53.3	20	1271	11.1	0	NA	NA	NA	NA	NA
		2B			56.3									
		3	2,093	6.2	33.5									

Appendix D
Coal Bed Methane Parameters Used to Evaluate Potential Impacts to Surface Water Quality

			Wyoming Input						Montana Input					
Sub-watershed	Stream Guage Location	Alternative	WY Number of CBM Wells	Average CBM Well Discharge Rate (gpm)	Managed Water Loss (percent)	Channel Loss (percent)	CBM Produced Water EC (uS/cm)	CBM Produced Water SAR	MT Number of CBM Wells	Average CBM Well Discharge Rate (gpm)	Managed Water Loss (percent)	Channel Loss (percent)	CBM Produced Water EC (uS/cm)	CBM Produced Water SAR
Montana Streams														
Upper Tongue River	Tongue River at Stateline near Decker, MT	A	1,948	6.2	85.3	20	2406	38.7	120	6.2	0.0	20	2207 - 2406	38.7 - 47.0
		C							530		0			
		D							530		0			
		E							120		0.0			
	Tongue River at Birney Day School, near Birney, MT	A	1,948	6.2	85.3	20	2406	38.7	2,424	6.2	87.7	20	2207 - 2406	38.7 - 47.0
		C									0			
		D									0			
		E									87.7			
Lower Tongue River	Tongue River below Brandenberg Bridge near Ashland, MT	A	1,948	6.2	85.3	20	2406	38.7	4,935	6.2	93.9	20	2207 - 2406	38.7 - 47.0
		C									0			
		D									0			
		E									93.9			
Middle Powder River	Powder River at Moorhead, MT	A	21,047	6.2	65.9	20	2370	21.8	568	6.2	100	20	2077 - 3042	24.8 - 41.9
		C									0			
		D									0			
		E									0			
Lower Powder River	Powder River at Locate, MT	A	21,047	6.2	65.9	20	2370	21.8	1,308	6.2	100	20	2077 - 3042	24.8 - 41.9
		C									0			
		D									0			
		E									0			
Mizpah Creek	Mizpah Creek at Mizpah, MT	A	NA	NA	NA	NA	NA	NA	66	6.2	100	20	1271 - 2077	11.1 - 24.8
		C									0			
		D									0			
		E									0			
Little Bighorn River	Little Bighorn River at Stateline near Wyola, MT	A	NA	NA	NA	NA	NA	NA	472	6.2	100	20	2207 - 2406	38.7 - 47.0
		C									0			
		D									0			
		E									0			
	Little Bighorn River near Hardin, MT	A	NA	NA	NA	NA	NA	NA	944	6.2	100	20	2207 - 2406	38.7 - 47.0
		C									0			
		D									0			
		E									0			
Bighorn River	Bighorn River at Bighorn, MT	A	NA	NA	NA	NA	NA	NA	1,737	6.2	100	20	2207 - 2406	38.7 - 47.0
		C									0			
		D									0			
		E									0			
Rosebud Creek	Rosebud Creek at Reservation boundary, near Kirby, MT	A	NA	NA	NA	NA	NA	NA	1,821	6.2	100	20	2207 - 2406	38.7 - 47.0
		C									0			
		D									0			
		E									100			
	Rosebud Creek at mouth, near Rosebud, MT	A	NA	NA	NA	NA	NA	NA	3,642	6.2	100	20	2207 - 2406	38.7 - 47.0
		C									0			
		D									0			
		E									100			

Appendix D
Coal Bed Methane Parameters Used to Evaluate Potential Impacts to Surface Water Quality

			Wyoming Input						Montana Input					
Sub-watershed	Stream Guage Location	Alternative	WY Number of CBM Wells	Average CBM Well Discharge Rate (gpm)	Managed Water Loss (percent)	Channel Loss (percent)	CBM Produced Water EC (uS/cm)	CBM Produced Water SAR	MT Number of CBM Wells	Average CBM Well Discharge Rate (gpm)	Managed Water Loss (percent)	Channel Loss (percent)	CBM Produced Water EC (uS/cm)	CBM Produced Water SAR
Lower Yellowstone-Sunday	Yellowstone River at Forsyth, MT	A	NA	NA	NA	NA	NA	NA	2,756	6.2	100	20	2207 - 2406	38.7 - 47.0
		C									0			
		D									0			
		E									0			
Lower Yellowstone	Yellowstone River near Sidney, MT	A	25,538	6.2	83.9	20	2406	38.7	4,064	6.2	100	20	2207 - 2406	38.7 - 47.0
		C									0			
		D									0			
		E									0			

APPENDIX E

Comparison of Surface Water Model Predictions with Actual Observed Data

Comparison of Surface Water Model Predictions With Actual Observed Data:
Powder River Oil and Gas Preliminary Final Environmental Impact Statement
By: Joe Meyer – U.S. Bureau of Land Management – Casper Field Office

Introduction:

The Powder River Oil and Gas Preliminary Final Environmental Impact Statement (PFEIS) utilized a spreadsheet based mass balance model developed by the United States Environmental Protection Agency (EPA) to analyze potential surface water impacts resulting from the discharge of coalbed methane (CBM) produced water. The surface water mass balance model predicts potentially significant changes in water quality for some watersheds at maximum predicted development (Figures 1,2,3). Given the relatively simplistic nature of the mass balance model, concern has been raised regarding the ability of the model to accurately predict stream water quality.

Model Predictions:

As previously mentioned, the EPA spreadsheet based model utilizes a simple mass balance approach to impact analysis. Using a mass balance technique completely ignores geochemical processes that occur as produced water moves from the point of discharge to the mainstem streams. Since much of the water discharge in the Powder River Basin passes through impoundments, or flows down ephemeral channels, the effect of transport chemistry on resultant water quality can be significant.

To evaluate the ability of the mass balance model to predict resultant water quality, CBM produced water discharge was computed for Powder River at Moorhead, MT (06324500)(Wyoming production only), Little Powder River above Dry Creek near Weston, WY (06324970), and the Belle Fourche River below Moorcroft, WY (06426500) for the entire period of CBM produced water discharge in those watersheds (Table 1).

Comparison of Surface Water Model Predictions With Actual Observed Data:
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Figure 1. EPA Mass Balance Model Predictions Powder River Moorhead, PFEIS Alt. 2B.

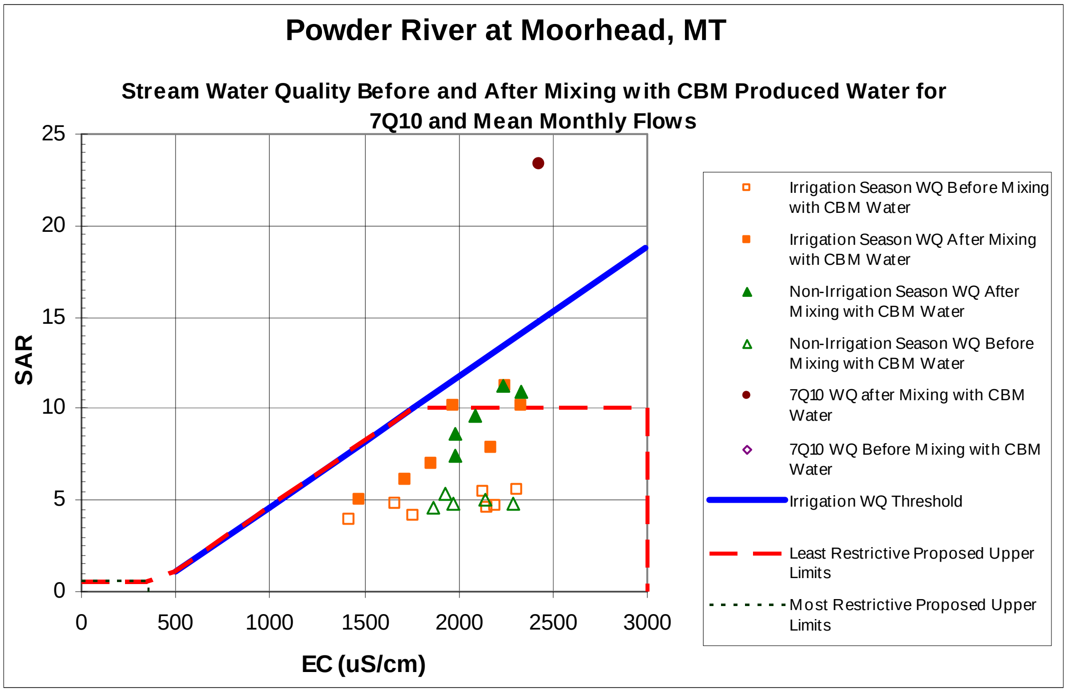

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Figure 2. EPA Mass Balance Model Prediction Little Powder River Weston, PFEIS Alt. 2B.

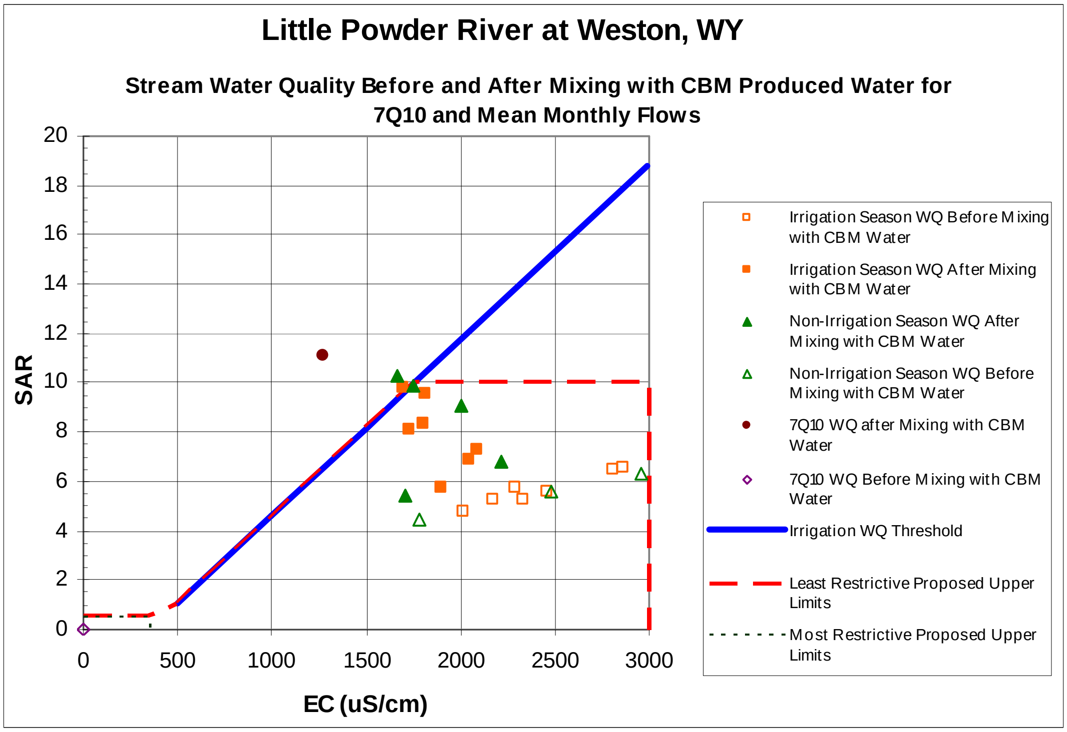
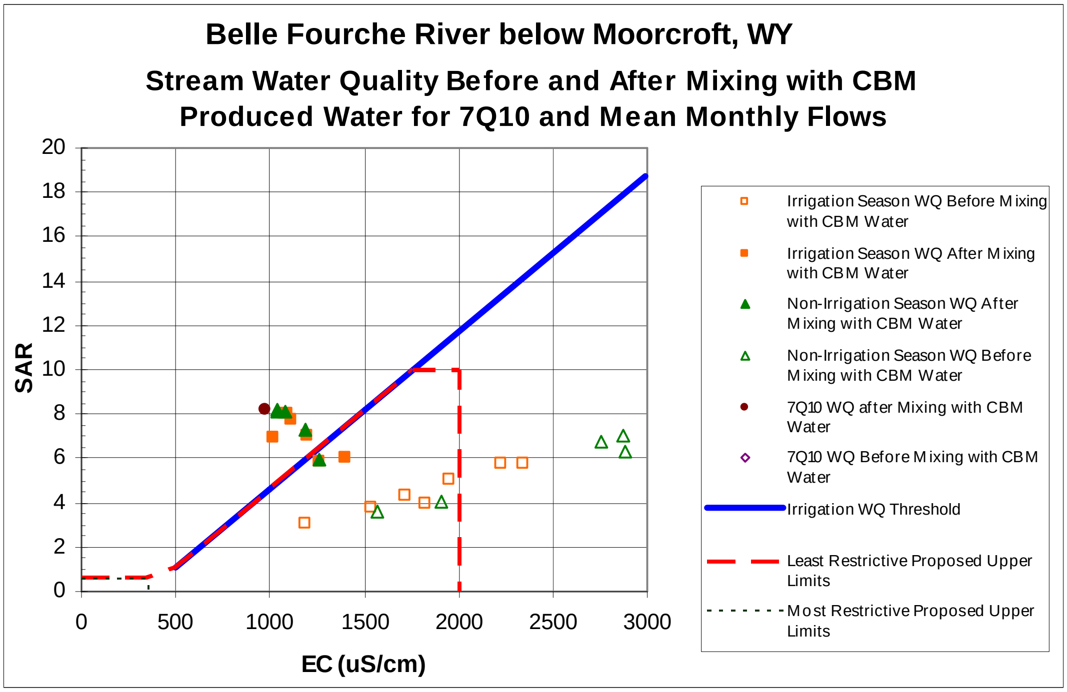


Figure 3. EPA Mass Balance Model Predictions Belle Fourche Moorcroft, PFEIS Alt. 2A.



Comparison of Surface Water Model Predictions With Actual Observed Data:
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Table 1 lists CBM water production values for the three basins for 2001. These values were input into the EPA mass balance model, and resultant stream water quality was predicted for each of the basins for the year 2001. There was too little CBM production in the Powder River Basin above Moorhead to show any significant change in resultant stream water quality with either the model predictions, or actual observed data (Figure 4, 5,6)

The mass balance model predictions for the Little Powder River using 2001 actual CBM produced water volumes indicate a significant change in resultant stream water quality (Figures 7,8,9). Graphical comparison of actual water quality samples collected by the United States Geological Survey (USGS) to the ambient mean monthly water quality at this station do not indicate any change in ambient stream water quality despite the fact that CBM produced water has been discharged in the Little Powder watershed since 1993, and the 2001 reported CBM produced water is equivalent to approximately 37 percent of the PFEIS predicted maximum CBM produced water discharge for this basin (Table 1).

A similar pattern is obvious in the model predictions for the Belle Fourche River below Moorcroft, WY (Figures 10,11,12). The mass balance model predicts a significant change in stream water quality as a result of CBM produced water discharge, and four months are predicted to exceed the Ayres – Westcott Line. Graphical comparison of actual water quality samples collected by the USGS to the ambient mean monthly water quality at this station do not indicate any change in ambient stream water quality despite the fact that CBM produced water has been discharged in the Belle Fourche watershed since 1993, and the 2001 reported CBM produced water is equivalent to approximately 33 percent of the PFEIS predicted maximum CBM produced water discharge for this basin (Table 1).

An attempt was made to conduct a more quantitative analysis of changes in ambient stream quality beyond the graphical comparison evident in Figures 7-12. Water quality data from USGS stations on the Belle Fourche River below Moorcroft, WY and Little Powder River Near Weston, WY were analyzed for two time periods, 1980 to 1992, and 1993 to 2001. These time periods correspond to the period of record available before and after CBM discharge in the basins. A plot of EC versus SAR was made for each station utilizing samples from the period prior to CBM discharge (Figures 13, 14). A linear trend line was then fitted to the pre CBM production samples. Using the equation of the trend line, SAR values were predicted for each EC value in the data set, both pre and post CBM development. A residual value was computed by subtracting the predicted value of SAR from the actual measured water quality. A positive residual value indicates that the predicted value of SAR is less than the actual measured value, and a negative residual indicates the predicted SAR is greater than the actual measured value. Most residual values for samples collected during the post 1993 period are negative (Figures 15,16), indicating that the EC / SAR relationship which existed prior to CBM production over predicts the SAR at any given EC value after CBM produced water has been discharged.

Residual values of predicted SAR for both stations (Table 2) seem to indicate that since the onset of CBM produced water discharge, SAR values at any given EC in the stream have actually decreased. This trend in EC / SAR does not follow the mass balance model which predicts increases in SAR in receiving streams as a result of CBM produced water discharge.

Further analysis of the measured water quality data was conducted to attempt to explain the apparent change in the EC / SAR relationship from 1993 to 2001. Samples collected during the period of 1993 to 2001 on average appear to have been collected at higher streamflow rates than the samples collected during the period of 1980 to 1992 (Table 3). USGS streamflow data from Powder River Moorhead, Belle Fourche Moorcroft and Little Powder Weston also indicate that mean annual streamflow was greater for water years 1993 to 2001 than they were during the water year 1980 to 1992 (Table 4). Precipitation records from Gillette, WY indicate that the average annual precipitation during the period of 1980 to 1992 was lower than the period of 1993 to 2001 (Table 5).

Comparison of streamflow records from stations with unequal periods of record, or comparison of two periods of record from the same station of unequal length can be difficult. Large variations in climate and streamflow in ephemeral systems can make statistical comparisons suspect. Streamflow rates obtained with water quality samples, annual mean streamflow records, and precipitation data all seem to support the trend of higher streamflow during the period of 1993 to 2001. It is likely that this higher streamflow is a result of greater precipitation rather than CBM produced water. Periods of higher precipitation and streamflow could account for a change in the EC / SAR relationship and account for the apparent lower SAR values during this period.

There is however, no evidence to support an increase in SAR in ambient water quality on the Belle Fourche River below Moorcroft, WY, or on the Little Powder River near Weston, WY despite significant CBM discharges during the period of 1993 to 2001. This is contrary to what is predicted by the EPA mass balance model.

Conclusions:

The mass balance model used in this analysis is a tool for comparison of alternatives, and analysis of relative contributions of cumulative impacts. However, due to a lack of data regarding chemical transport relationships and conveyance loss it may not accurately predict likely impacts on resultant water quality. Samples collected since the onset of CBM production in the Belle Fourche and Little Powder River Basins have not detected changes in ambient stream water quality which were predicted by the mass balance model, and actual impacts may be less then the mass balance model predicts. The magnitude of the model results can not be verified based upon actual measured water quality data. Adequate protection of existing uses and water quality standards can only be accomplished through direct monitoring of stream water quality to measure the effects of CBM discharge.

Comparison of Surface Water Model Predictions With Actual Observed Data:
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Table 1. Average Number of Producing CBM Wells and Rate by Basin.

Basin	Year	Average Number of Producing CBM Wells	Average Rate (gpm)	CBM Discharge as % of Predicted Maximum
Belle Fourche River Below Moorcroft (06426500)	1993	32	8.08	0.48
	1994	53	9.56	0.96
	1995	65	13.84	1.69
	1996	87	11.93	1.94
	1997	164	15.15	4.64
	1998	287	12.99	6.99
	1999	566	10.88	11.52
	2000	1557	9.05	26.38
	2001	2818	6.28	33.11
Little Powder River above Dry Creek near Weston, WY (06324970)	1993	13	4.71	0.38
	1994	7	4.92	0.21
	1995	7	10.76	0.49
	1996	10	15.41	1.01
	1997	24	13.73	2.10
	1998	45	12.73	3.67
	1999	116	14.30	10.50
	2000	525	9.23	30.74
	2001	1050	5.57	37.07
Powder River at Moorhead, MT (06324500)	1993	0		
(Wyoming Production Only)	1994	0		
	1995	0		
	1996	0		
	1997	0		
	1998	0		
	1999	46	25.15	0.89
	2000	357	9.66	2.64
	2001	1243	6.49	6.18

Figure 4. Mass Balance Prediction Using 2001 Actual CBM Production.

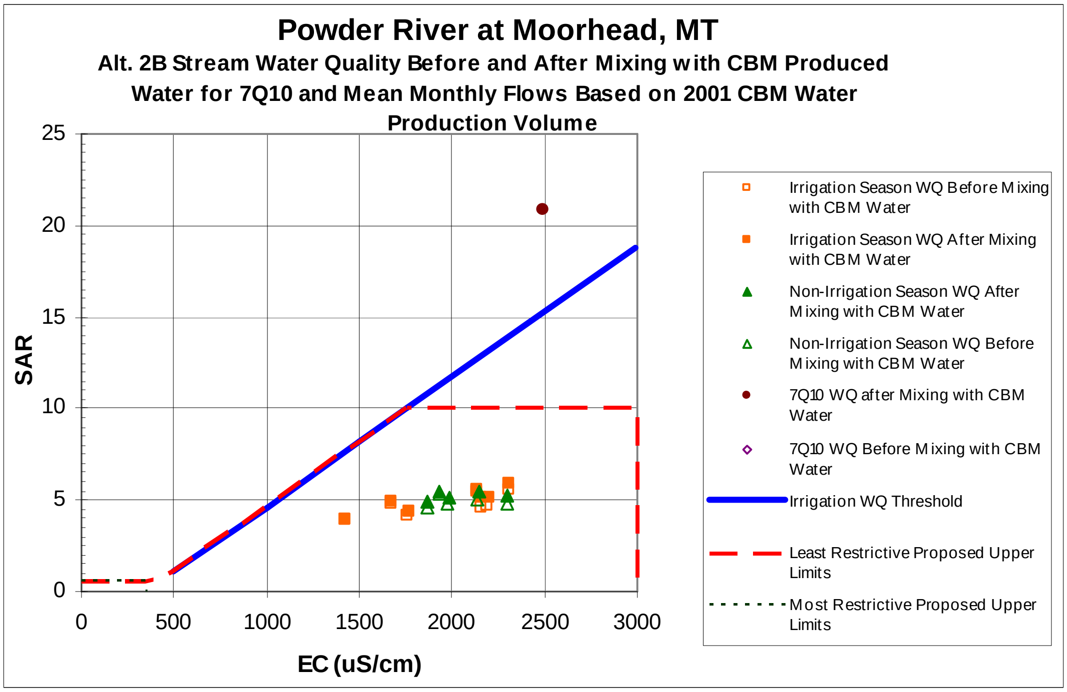
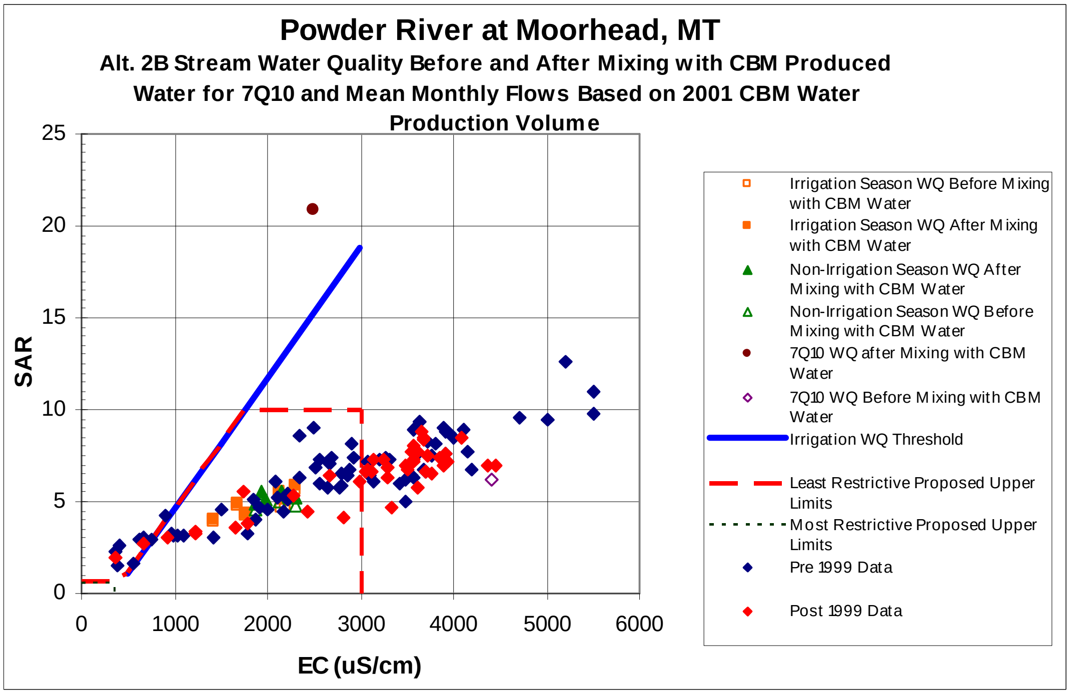


Figure 5. Mass Balance Prediction With Measured QW Samples.



Comparison of Surface Water Model Predictions With Actual Observed Data:
Powder River Oil and Gas Preliminary Final Environmental Impact Statement
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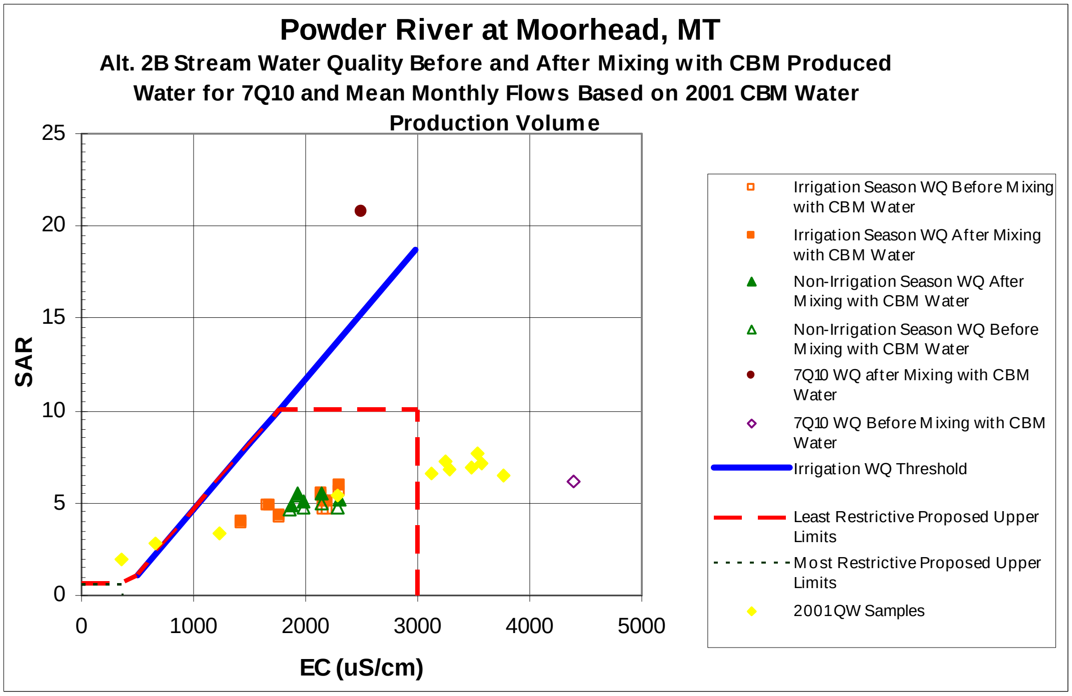
Figure 6. Mass Balance Prediction With 2001 Measured QW Samples Only.



Comparison of Surface Water Model Predictions With Actual Observed Data:
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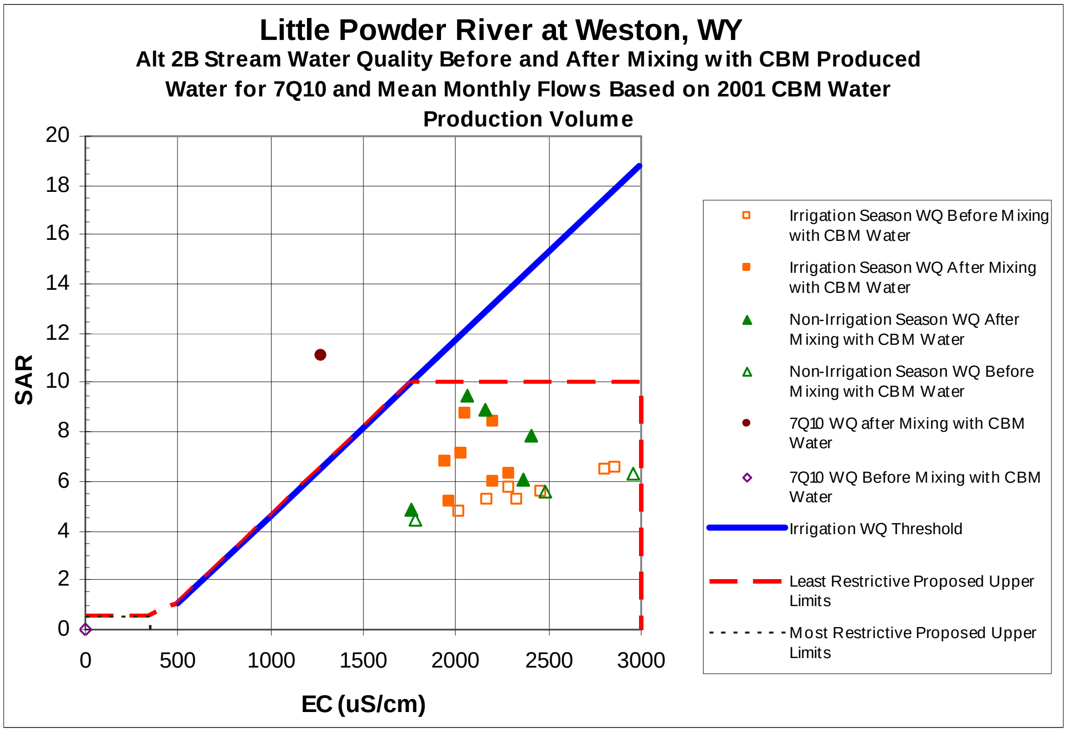
Figure 7. Mass Balance Model Prediction Using Actual 2001 CBM Produced Water Volumes.



Comparison of Surface Water Model Predictions With Actual Observed Data:
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Figure 8. Mass Balance Model Prediction for 2001 With Actual QW Samples.

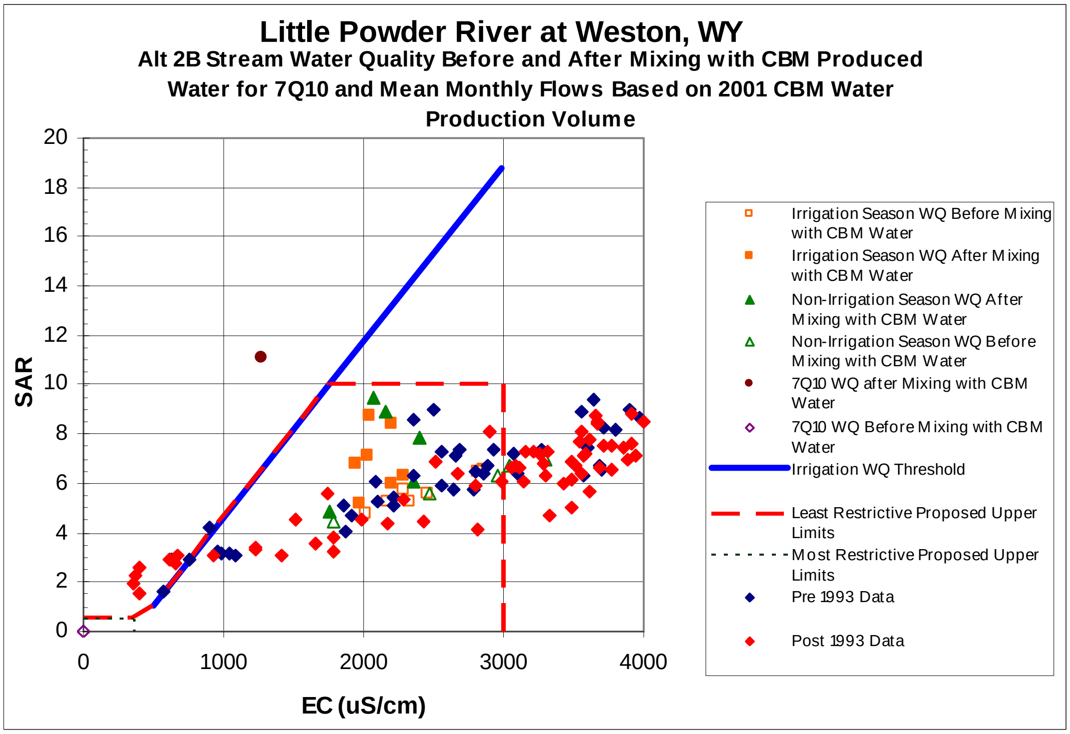
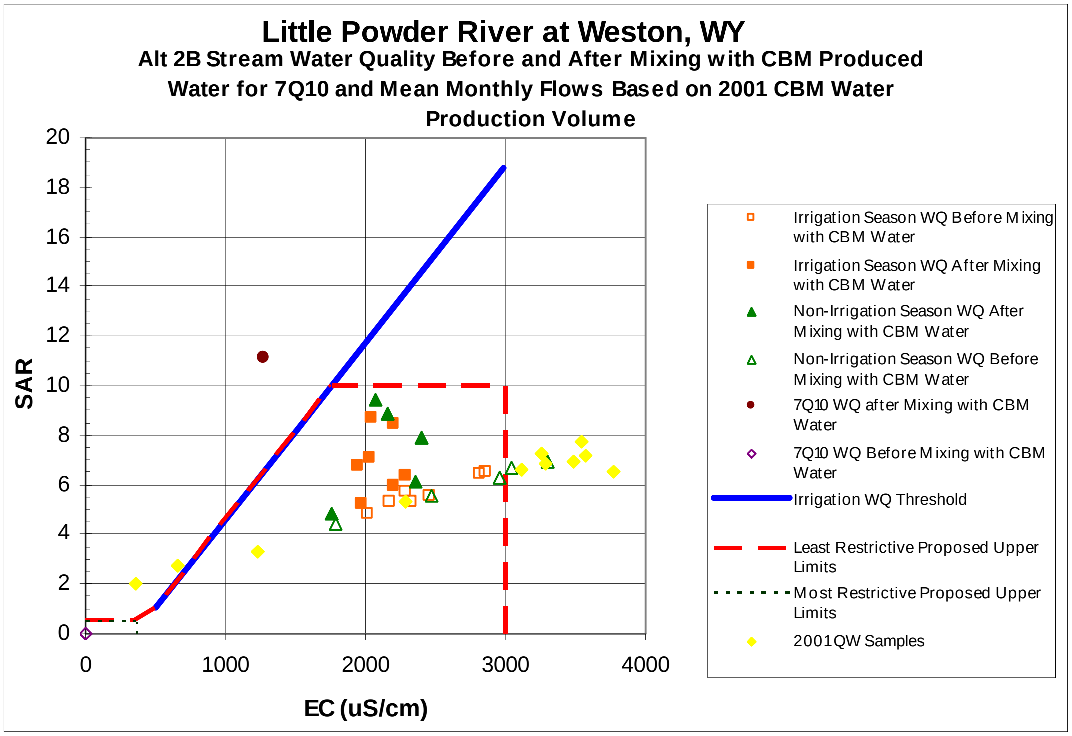


Figure 9. Mass Balance Prediction With 2001 Actual QW Samples.



Comparison of Surface Water Model Predictions With Actual Observed Data:
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Figure 10. Mass Balance Model Prediction River Using 2001 Actual CBM Produced Water Volumes.

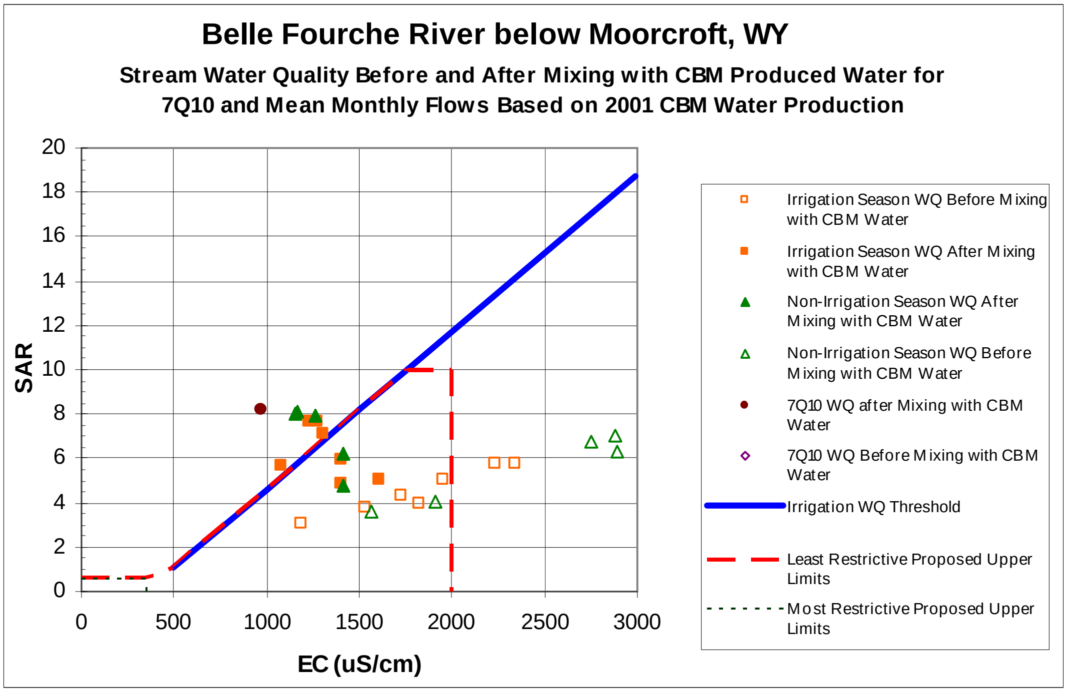

Figure 11. Mass Balance Model Predictions With Actual QW Samples.

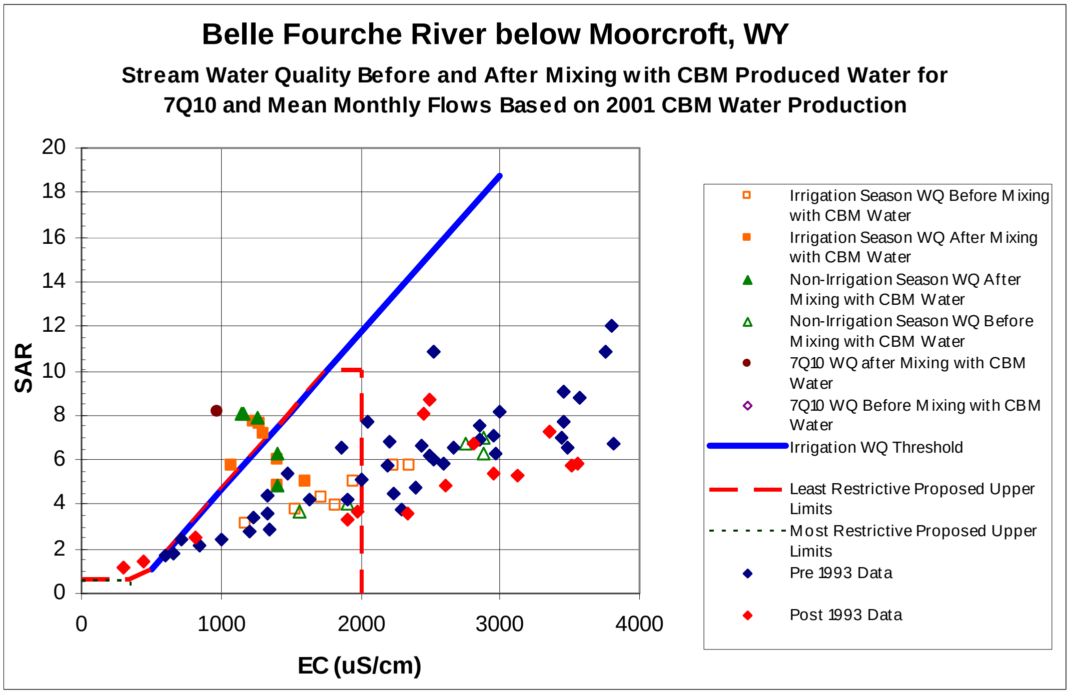

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Figure 12. Mass Balance Model Predictions With 2001 Actual QW Samples.

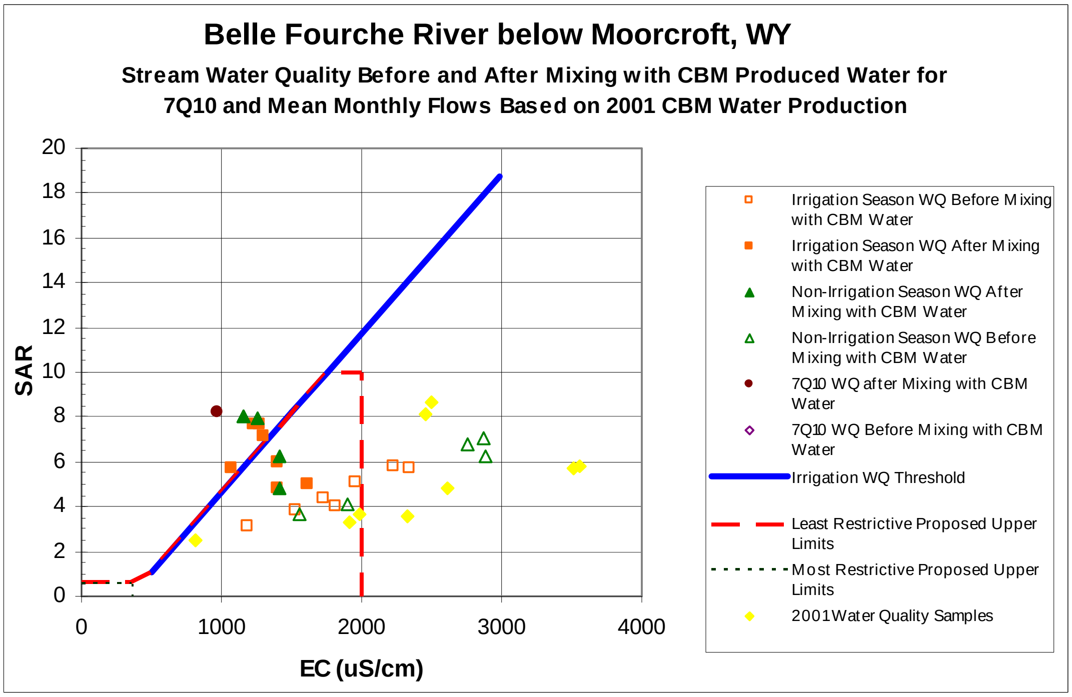

Figure 13. EC - SAR Relationship for Little Powder Weston.

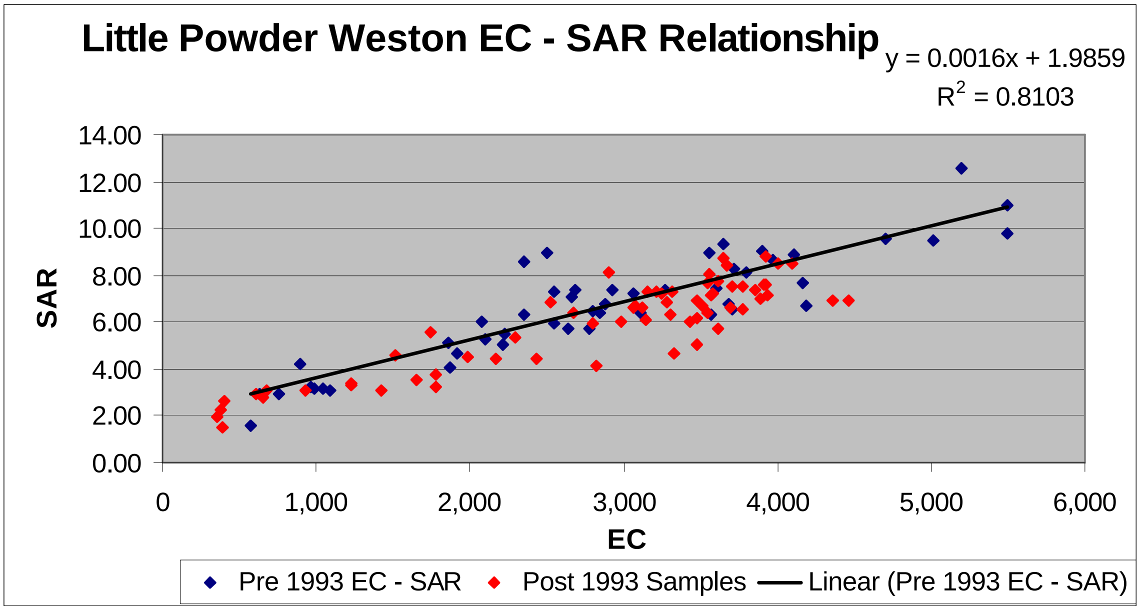

Figure 14. EC - SAR Relationship for Belle Fourche River Below Moorcroft.

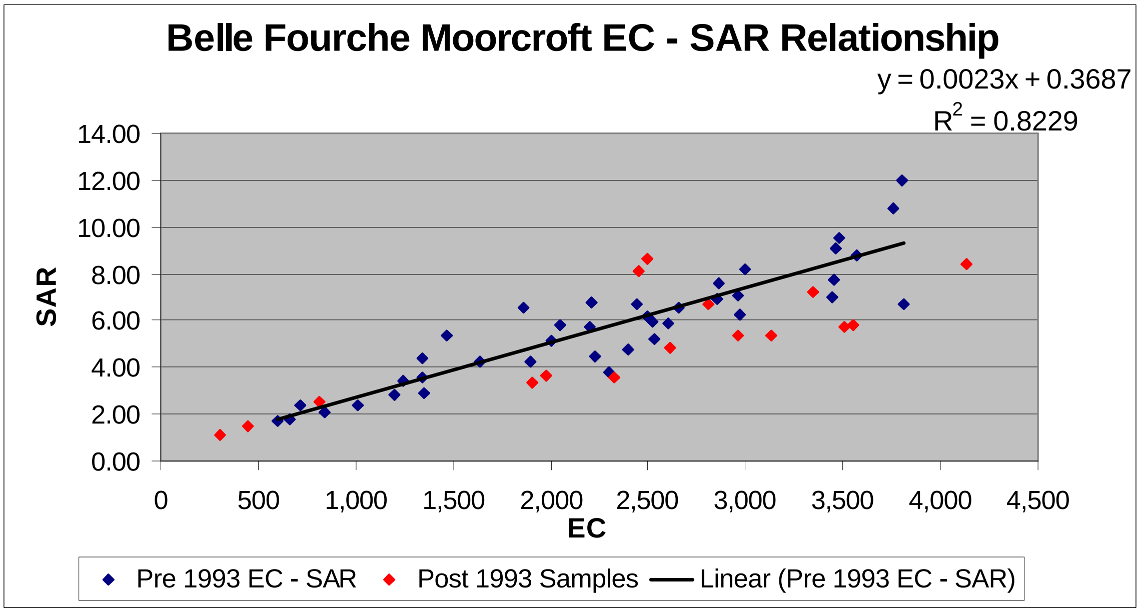

Figure 15. Residual Values For Predicted SAR.

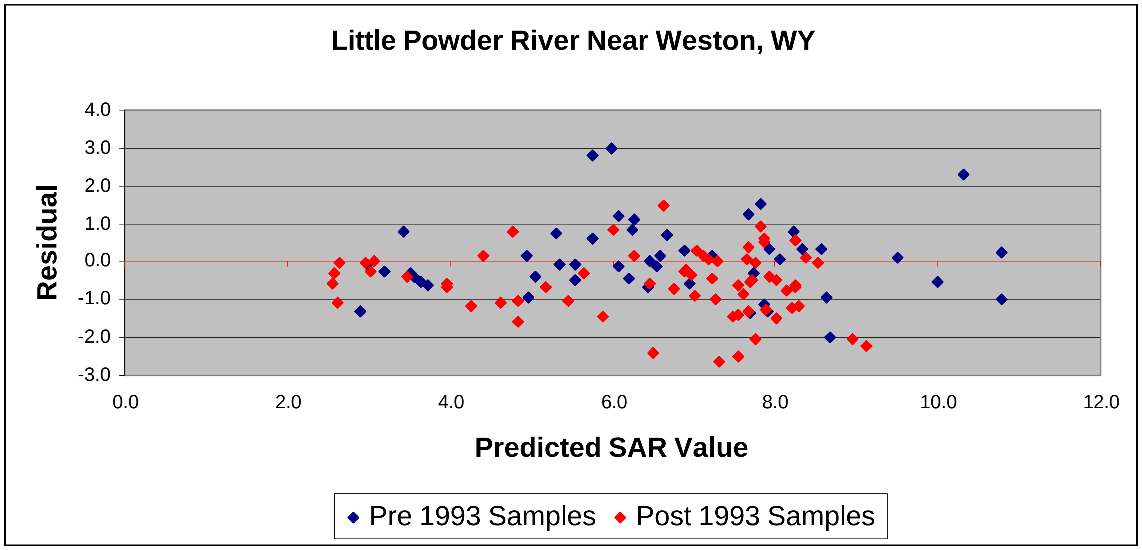

Figure 16. Residual Values for Predicted SAR.

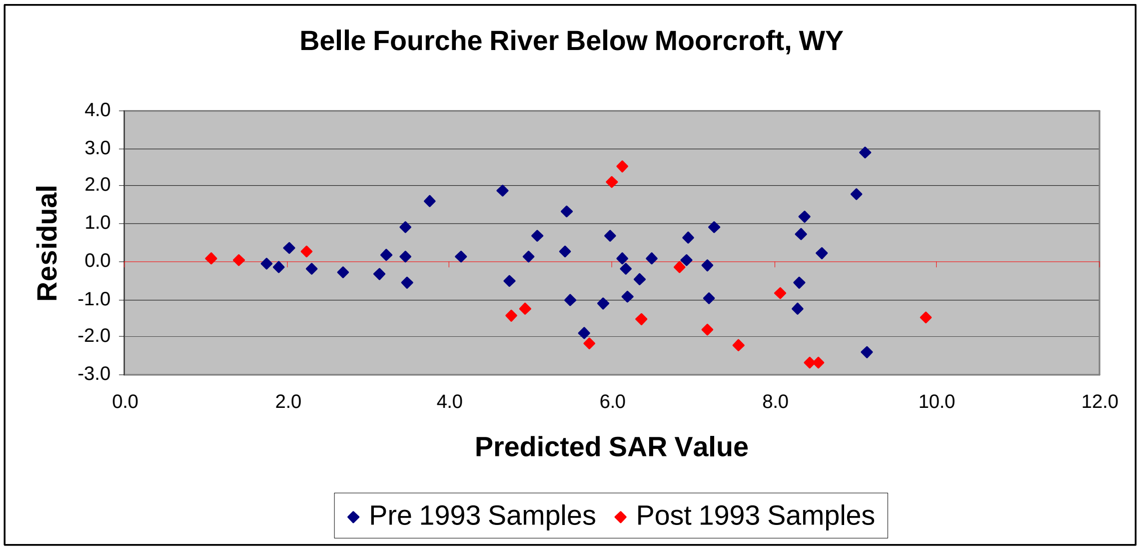

Table 2. Residual Values of Predicted SAR.

Station	Period	Standard Deviation of Residuals	Average Of Residuals
Belle Fourche Moorcroft	1980 to 1992	1.02	0.10
Belle Fourche Moorcroft	1993 to 2001	1.55	-0.82
Little Powder Weston	1980 to 1992	1.01	0.08
Little Powder Weston	1993 to 2001	0.85	-0.58

Table 3. Measured Streamflow of QW Samples.

Period	Belle Fourche Moorcroft	Little Powder Weston
Pre 1993 Average QW Sample Discharge	21.55	32.43
Pre 1993 Median QW Sample Discharge	1.50	1.20
Post 1993 Average QW Sample Discharge	114.07	46.97
Post 1993 Median QW Sample Discharge	8.50	7.30

Table 4. Mean of Annual Mean Discharge.

	Station 06324500 Powder River at Moorhead, MT	Station 06324970 Little Powder River above Dry Creek near Weston, WY	Station 06426500 Belle Fourche River below Moorcroft, WY
Mean - Annual Mean Discharge 1980 to 1992 Water Year	372.6	12.7	16.9
Median - Annual Mean Discharge 1980 to 1992 Water Year	359.1	9.6	16.5
Mean - Annual Mean Discharge 1993 to 2001 Water Year	492.8	30.0	28.5
Median - Annual Mean Discharge 1993 to 2001 Water Year	503.9	26.6	32.1

Table 5. Average Annual Precipitation - Gillette, WY

Station: Gillette 9 ESE, Wyoming	
Year	Preciptiation (Inches)
1980	14.77
1981	13.45
1982	26.37
1983	12.75
1984	14.25
1985	14.07
1986	17.35
1987	16.50
1988	12.56
1989	15.31
1990	12.72
1991	14.88
1992	11.67
1993	25.34
1994	18.79
1995	19.80
1996	19.48
1997	19.67
1998	23.56
1999	18.41
2000	14.62
2001	15.87
Average Annual Precipitation 1980 to 1992	15.13
Average Annual Precipitation 1993 to 2001	19.50

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Please reference the following files for detailed data:

Powder_Little_Powder_2001_Model_Prediction.xls - Re-run of the EPA mass balance model using actual 2001 CBM production for Powder and Little Powder River stations.

Belle_Fourche_2001_Model_Prediction.xls - Re-run of the EPA mass balance model using actual 2001 CBM production for the Belle Fourche Moorcroft Station.

Belle_Fourche_Little_Powder_EC_SAR_Analysis.xls – Contains QW data, analysis of EC / SAR relationships, CBM produced water volumes, streamflow volumes and precipitation data.